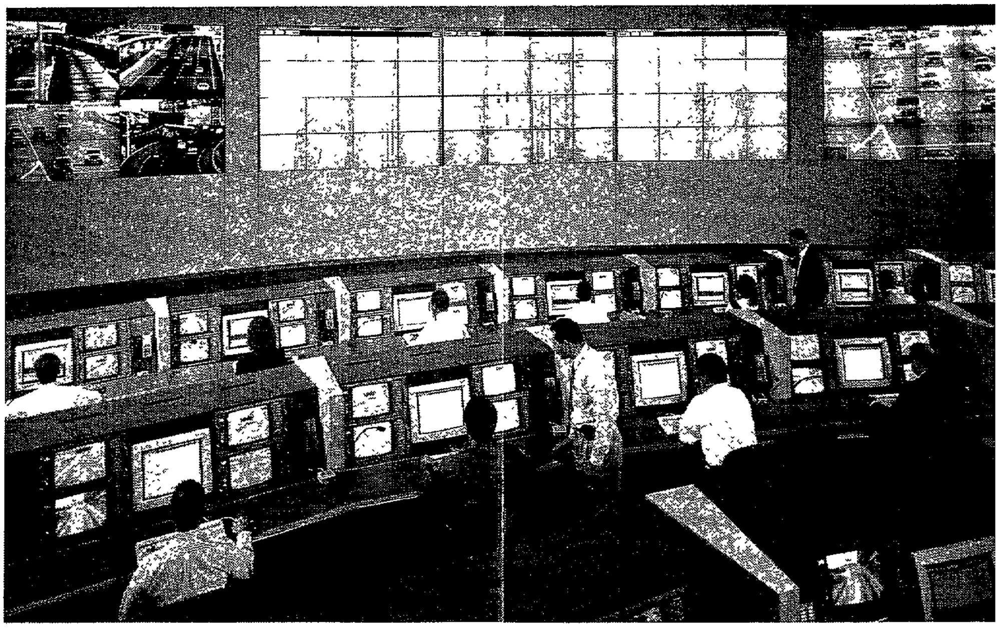
5.0 Description of the TransGuide ATMS Design



> ***"The San Antonio District of TxDOT designed the system and then received feedback from other technically competent organizations . ... We went through several cycles to make sure that the system was not proprietary to any one organization."***
>
> *Member of TxDOT's TransGuide Design Team*

Once the requirements for the TransGuide ITS were determined, a formal specification for the system was generated. That specification was used in the procurement of the system and was a basis for the detailed design of the system. The TransGuide detailed plans and specification included the electronics, cables, signs, control center building, and highway work required to install the system components. The intent was to include everything required to get TransGuide up and running. This chapter describes the overall system design performed by the San Antonio District of the Texas Department of Transportation and each of the major functional components of the system, as well as aspects of the TransGuide system related to its operational capabilities. Section 5.1 describes some overall system issues. Sections 5.2 and 5.3 discuss incident detection, verification and characterization, and the video subsystem used in verification and characterization. Sections 5.4,5.5, and 5.6 discuss major TransGuide subsections: communications, computer, and traffic information and control. The last section, 5.7, discusses the operator and manager interfaces.

Two types of tables appear in this chapter. Some contain decision matrices, which indicate the alternatives available or investigated and characteristics relevant to making a selection among them. The other tables provide information on characteristics or numbers of selected equipment.

5.1 System Issues

TransGuide consists of several subsystems used in a well-defined process to detect, classify and respond to incidents on the freeway system. Section 5.1.1 discusses the overall process defined for TransGuide systems operation. Section 5.1.2 discusses the physical and logical organization of the TransGuide system itself. Section 5.1.3 discusses a variety of issues concerning the development and maintenance of the software that provides the basis for TransGuide system operations. Section 5.1.4 discusses the various levels of redundancy and fault tolerance in the subsystems.

5.1.1 Overall TransGuide Operational Process

Table 5.1.1-l lists several alternative processes for traffic control center operations, as well as some of the characteristics considered in selecting the process implemented in the TransGuide system. There are several defining characteristics on which the TransGuide designers focused. One such characteristic is the primary operational focus of the TransGuide system. Another is the efficient use of the field assets. A third characteristic which drove the TransGuide system design is its focus on emergency responses. These operational characteristics mandated another significant characteristic of the TransGuide system, its emphasis on full coverage, high quality video.

Many TMCs are focused on detecting congestion. They generally determine the congestion of segments of the freeway by comparing traffic pa-

TABLE 5.1.1 -1 - Operational Approach Decision Matrix

Defining Characteristic		• Incident detection • Scenario asset control • Full Coverage Video • Emergency Dispatch	• Congestion detection • Individual asset control . Critical area video coverage • Support emergency agencies	• Ramp metering control • Automatic ramp metering with manual override • Metering based video coverage • Support emergency agencies
Resulting Characteristic	Priority			
Response Speed	Very high	Rapid, minimal automatic detection time combined with minimal equipment modification time	Moderate, some delays expected in verifying and classifying incidents and in specifying the response	Moderate but variable, response time depends on traffic densities and highway geometries
Response accuracy	Very high	Very high, complete high quality video coverage provides confidence in response	High, accurate response may require some additional delays in responding	Moderate, depends on sources used to classify the incidents
Expandability	Very high	Very high, no major impediments to expansion	High, no major impediments to expansion	Very high, significant coverage required for good operation
Operational cost	Very high	Moderate, scenarios minimize staffing and training requirements	Moderate, requires a small number of well-trained staff	Low, most of system operations are automated
Flexibility	High	Very high, full video coverage and complete control of signs	Moderate, responses can only be based on available information	Low, system is primarily automatic
Installation cost	High	Moderately high, full video coverage and consistent trap configuration for loop detectors	Moderate, combined video and detector installation	Moderately high, video, detector, and ramp meter installation
Response supportability	High	Very high, high quality video provides capability to determine precise response	Moderately high, a variety of inputs can facilitate slightly delayed responses	Very high, response is automatic

rameters such as occupancy, volume or speed to some set of thresholds. Other TMCs focus on the use of ramp metering to control the volume of vehicles on the freeways. An alternative focus is the detection of and response to incidents. Since one of the primary causes of congestion in San Antonio is incidents, that is a focus of the TransGuide system. The focus on incident detection, as opposed to congestion detection, is illustrated by the capability of the system to compare traffic speeds and volumes to dynamically varying thresholds rather than to a single static threshold. It is also illustrated by the use of loop detectors only for the detection, rather than both the detection and classification of incidents.

Many systems interact with traffic primarily through signs which are controlled on a sign-by-sign basis. Other systems interact with traffic via ramp meters which are automatically controlled. A third alternative is the use of pm-engineered, multiple asset scenarios to respond to incidents. The TransGuide system is designed to be able to select and execute scenarios involving many signs, signals and light controllers with a few mouse clicks. The development of scenarios was discussed in Chapter 4 and the selection and implementation of scenarios in real time in the TransGuide system is discussed in the Traffic Management System Interface section of this chapter below.

While almost every TMC supports the agencies who respond to emergencies on the freeways, the TransGuide system has been specifically designed to provide a center for responses to emergency situations. Location of police, emergency and transit dispatch functions in the TOC itself provides the synergy necessary to optimize the response.

The availability of video with the coverage and clarity necessary for use in incident verification and classification and in coordinating emergency response drove many of the TransGuide system design decisions. In the past, the technology to install full coverage video systems along the highway and transmit real-time video to a traffic management center was too complex and expensive to be feasible. As communications technologies have improved, designers have utilized the improved technologies to provide more and better video at TMCs. Initially many centers had to cope with controlling traffic using very little or no video. Video was then added in the most critical areas. The TransGuide system has been designed to provide full video coverage throughout the instrumented portions of the freeway system.

Figure 5.1.1-l provides a summary of typical sensors and the operator interfaces used by the TransGuide system. The initial incident detection sensors are loop detectors. The sensors are read by Local Control Units (LCU), which derive traffic parameter information and transmit the information

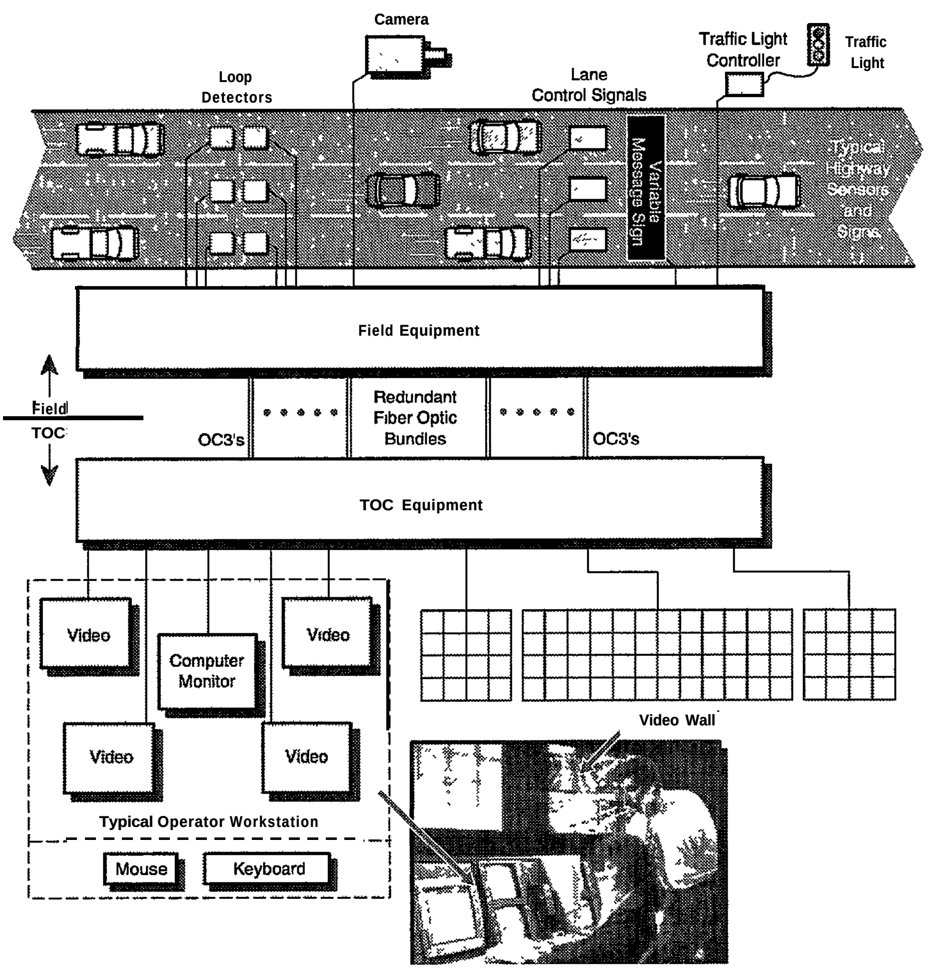


Figure 5.1.1- 1 - Typical TransGuide Interfaces

via the optical network to the mainframe computer at the TOC. The mainframe computer combines traffic data with threshold information to generate alarms. The alarms are displayed via the Local Area Network (LAN) in the TOC on the manager's and operators' terminal screens.

Real-time video of traffic scenes is collected by a user controllable camera and lens system. The video is transmitted to the control center via an optical network. Using digital communications and switching, the video is distributed to the workstations and to screen arrays on the video wall. Video from any of the cameras can be displayed on any of the four video monitors at each workstation or on one of the video walls. The TransGuide software facilitates camera use and aids the operator in selecting an appropriate response scenario. Once the operator selects a scenario, the system informs the driving public of the incident via VMSs and indicates which lanes are clear via LCSs. Traffic light controllers for access road intersections can also be instructed to modify the timing of light cycles.

The VMS, LCS, and traffic light controllers used by TransGuide to inform drivers and to control traffic will be augmented by other driver information services in the near future. Other sensors, including an incident detecting video based subsystem, may be added to TransGuide as they are developed and proven. The capability to add sensor types and to interface with additional traffic control and driver information systems was part of the driving force behind the design and development of the TransGuide system.

5.1.2 TransGuide Organization

There are a variety of ways to organize a traffic management system. Several different organizational structures, along with some characteristics of those organizations, are listed in Table 5.1.2-l. The TransGuide system is organized around a single TOC. All traffic management functions are performed at the TOC. All video signals are transmitted to the TOC. All TransGuide managers and operators are located at the TOC. All signs and signals are controlled from the TOC. The mainframe computer controlling the system is located at the TOC. The only distributed parts of

TABLE 5.1.2-I - System Architecture Decision Matrix

Characteristic	Priority	**Centralized TMC, all assets controlled from a single central facility**	Distributed TMCs, geographically dispersed,independent facilities which control local assets	Hierarchical TMCs, centrally controlled TMCs which control local assets
Expandability	**Very** high	Very high, as long as the initial design anticipates the expansion	Very high, additional TMCs can be added, as needed	Very high, additional distributed TMCs can be added if the central facility design anticipates the requirements
Flexibility	Very high	Very high, Any of the system assets can be used as situations warrant	LOW, coordination between TMCs can be difficult	Moderate, coordination between center may limit flexibility
Availability	Very high	High, if the central facility is designed with fault tolerance and redundancy	High, while all centers may not be up, most of the centers should be up at any one time	High, most of the centers should be up **at** any one time,the central TMC may require more fault tolerance.
Operational Cost	High	Moderate, single system allows many costs to be shared	High, each center must be **separately staffed**	High, each center must be separately staffed
Initial Cost	Medium	Moderate, only a single facility must be built, however, communications runs may be longer	High, separate facilities must be built for each center	High, separate facilities must be built for each center

the system are the sensors, detectors, signs, signals, communications, and local controllers.

One type of organization is a distributed system with no central TMC. In such a system the control of traffic is based on geographical location. Another is hierarchical, where there is some local control and some overall control. A third is centralized, like the TransGuide system, where all traffic is controlled from a single location. Each organization has advantages and disadvantages.

While a distributed system has a high probability of always being at least partially up, or operational, there is usually an increased probability that part of the system will be down. A distributed control system may allow the operator to concentrate on local, familiar parts of the system. However, it does not easily support sharing of resources between areas nor does it facilitate the solution of control problems that span the boundaries of the local areas.

The hierarchical system has some of the advantages and disadvantages of each of the other organizations. A hierarchical system provides both local control and control of overall problems. However, it is also the most complex and expensive to develop and implement. A hierarchical system may also be particularly subject to parts of the system being down due to the type and amount of equipment required in the implementation, as well as the environmental requirements of distributed equipment.

"The initial ideas included a system with nine separate control centers scattered throughout the city. Based on overall costs it was decided to go with one central control center. By eliminating the extra buildings, at least $4.5 million was saved initially."

Member of TxDOT's TransGuide Design Team

One of the primary advantages of a centralized system is the capability to share equipment and personnel among all of the tasks involved in traffic management. A centralized system also provides a single location for all equipment requiring environmental stability, as well as allowing operators to communicate easily about potentially interrelated problems. One of the primary potential disadvantages of a centralized system is the potential for the entire system to fail.

The TransGuide system has been designed specifically to take advantage of the features of a centralized system while avoiding the potential disadvantages. Significant effort was concentrated on minimizing the chances of loosing the capabilities of all, or a significant part of the TOC.

5.1.3 Software Issues

The software developed for the TransGuide system is critical to the success of the project. The software must successfully and reliably interact with all of the devices which are specified for the various subsystems of TransGuide. The software provides the operator and manager interfaces to the system. The software collects data from various devices and then assembles and analyzes it a central location. It alerts the operators to potential incidents and allows the operators to control the cameras and view data in a graphical environment to facilitate the evaluation the incident. The software lets the operator select and, if necessary, modify the scenarios used to control the VMSs and LCSs. The software also provides the tools necessary to maintain the TransGuide system and to modify the system as it grows and evolves.

Many software based functions are required to integrate and manage all of the other assets of the TransGuide system. The TransGuide software was developed as a number of independent, cooperative software processes. The mainframe utilized provides a multi-tasking environment in which a software architecture which utilizes a number of communicating processes can be easily implemented. In addition to the processes executed by the TransGuide system, the design and development of the system also required the development of databases which describe the system equipment and the scenarios which can use that equipment. A Graphical User Interface (GUT) was developed for the operators, managers and system administrators to allow users who are not computer experts to operate and maintain the TransGuide system.

The overall development of the TransGuide system was based on a set of standards to enhance the maintainability and supportability of the systern and to increase the reusability of the software developed for the system.

5.1.3.1 Data Acquisition

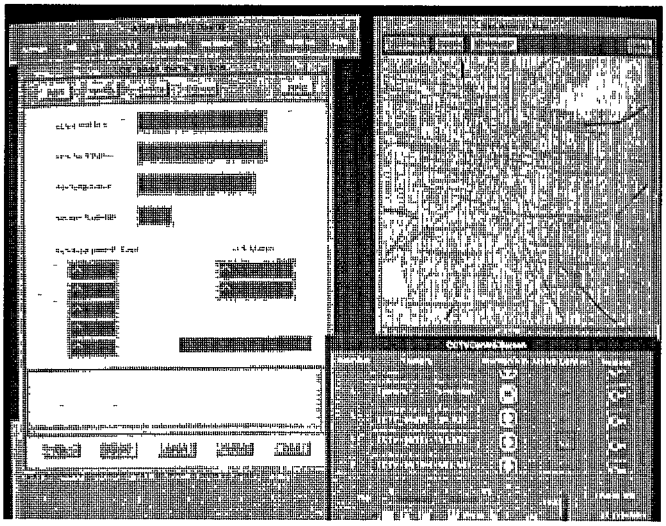
In order to provide managers, operators and ultimately drivers with information, the TransGuide system must first acquire data from the highways to determine whether traffic slowdowns have occurred. Data is collected by a variety of software processes which continually poll the LCUs for traffic information. Nominally, each loop detector is polled every twenty seconds. The software then applies various averaging algorithms to determine whether the current traffic is consistent with expected traffic patterns. The TransGuide software has the capability to allow the users to establish expected traffic patterns for specific times of day so that the generation of alarms can be adjusted based on expected traffic conditions.

The polling process described above occupies a significant amount of the processing time required by the TransGuide system. Personal Computers (PCs) have been added to the system to perform the LCU polling and data processing so that the TransGuide mainframe does not have to support the amounts of I/O needed to poll the LCUs.

The data collected in the polling process is stored in RAM on the TransGuide mainframe and not in a database. Short term data collected from the LCUs has very little historical value because it changes so rapidly. The software does have various mechanisms to capture the data when trend analysis is to be performed.

5.1.3.2 Databases

The database structure developed for the TransGuide system provides the foundation for the success of the software and, ultimately the system as a whole. With the hardware architecture utilized, the database on the mainframe is a centerpiece in the TransGuide data collection process The database contains information about each piece of field equipment utilized in the system. This information is utilized to establish communications parameters for the equipment and to control the data collection.



TransGuide GUI

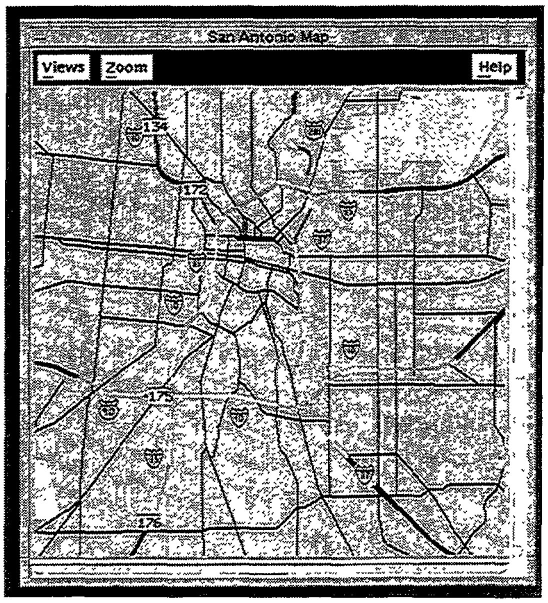
A database also contains the solution scenarios. The scenarios are stored in a relational database so that searches and retrievals of the scenarios can be performed in an efficient manner. High speed retrieval of the scenarios is essential to the systems ability to rapidly respond to incidents.

The TransGuide system also has a number of database editors which are essentially GUIs which provide an easy to use interface to the database. This architecture allows an individual to rapidly add, modify or delete data from the database without detailed knowledge of the irnplementation details of the database.

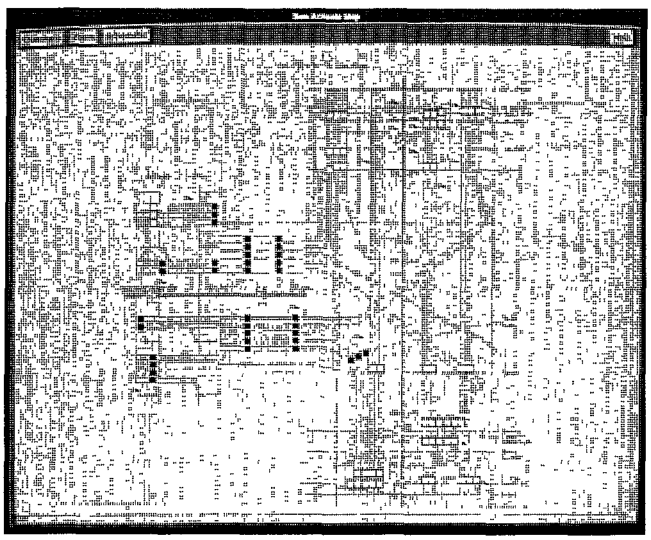
5.1.3.3 Graphical User Interface (GUI)

The Graphical User Interface (GUI) for the TransGuide system is based on OSF MOTIF. All user input is through a GUI and the GUIs were designed to be used by personnel with no computer programming experience. The GUIs provide the user with the capability to address alarms/scenarios, control VMSs and LCSs, and manipulate the cameras located throughout the TransGuide system. The database editor GUIs allow administrative personnel to keep the databases up-to-date as the TransGuide system grows and evolves. One of the GUIs developed for the system is a graphical map. For depiction of current traffic patterns, the TransGuide graphical map is essential. Two levels of the map exist, the high level and schematic level.

The high level map can display the entire San Antonio metropolitan area. Highways which are



San Antonio Map



Schematic Level Map Screen

instrumented by the TransGuide system are displayed in color (green, yellow and red) so that the observer can rapidly assess overall traffic conditions. The user can pan and zoom around the high level map. Major arterials and landmarks are provided on the map so that their influence on current traffic conditions can be reviewed by the TransGuide operators.

The user also has the ability to view a schematic level graphical map. The schematic level map details each individual lane and displays all the field equipment utilized by the TransGuide system. The user can display, in graphical format, current traffic flow conditions for each lane as well as the contents of each VMS and LCS. The schematic level map is utilized by TransGuide operators when they implement solution scenarios. When viewing the color coded schematic map (and the traffic flow data), it is quite easy to grasp traffic conditions so that field equipment can be set to improve traffic flow.

5.1.3.4 Software Development and Standards

As a complex system such as TransGuide is initially defined, it is difficult to appreciate the pervasiveness of software in the system. While most of the hardware components of the TransGuide system are commercially available and essentially off-the-shelf, significant portions of the software had to be developed specifically for the TransGuide system. Because much of the software for a traffic operation center must be custom developed, it requires significant planning and close cooperation between the users and the developers. The specifications developed by TxDOT mandated the development of a requirements specification document to facilitate the definition of the TransGuide software functionality. The specifications also required the use of specific standards in the development process.

Developing software for a complex system like TransGuide requires, not only extensive planning and coordinating, but also continuing reassessment as the system evolves and grows. The system will not operate and will not be useful until and unless the software is easily used, reliable and maintainable. The large amount of custom software required made the software development a key process in the success of the TransGuide system.

To ensure portability and interoperability with existing and future systems, and to increase system maintainability, TransGuide system software was required to meet certain standards. In some cases a specific standard was specified, but in other cases the contractor could choose from a list of standards. Some of the specified standards, along with comments on their applicability, are listed in Table 5.1.3-1. The use of standard languages and protocols ensures that the system can be maintained by personnel or contractors readily available to TxDOT.

The specifications required that the operating system be compliant with the POSIX standard. Compliance with POSIX will allow the code devel-

TABLE 5.1.3-l - Software Issues

Issue	Standards	Comments
Language	ANSI standard C,assembly	Assembly language is allowed only where required, and with engineer's approval.
Communications protocols	OSI,GOSIP orTCP/IP	These are a variety of standard communications protocols
Operating system	POSIX, XPG3	POSlX.1, POSIX.2, and POSIX.4 were required, but certain off-the-shelf applications were exempted. XPG3 is a set of standards.
User interface	OSF-MOTIF	OSF-MOTIF is one of the standard user interfaces used in UNIX and POSIX environments
Network management interface	CRAFT	CRAFT is the standard interface between telecommunications systems and their status and control systems. The central computer is also required to abide by the interface to the network management system.

oped for the TransGuide system to be ported to many of the computer platforms available today and will ensure a readily available pool of experienced software personnel for system maintenance and modification.

The programming language specified for the system was ANSI standard C. The C programming language is used in many systems being developed today, and most organizations capable of maintaining or upgrading TransGuide system software should have experienced C programmers. The specified ANSI standard version of C is portable to most computer platforms available and should continue to be supported by future computer systems. Minimizing the use of assembly language will also increase system maintainability and portability

The use of standard communications protocols provides a wide selection for the components needed to implement the system and any later additions to the system. The communications protocol used in the LAN is TCP/IP. The LAN is the system over which the computers and workstations at the TOC communicate, and TCP/IP is a widely used standard for communicating between computer systems. The selection of the much more widely used TCP/IP protocols rather than a proprietary protocol or a protocol which is not as widely used provides TxDOT with a wider selection for additional or replacement equipment.

The use of a standard user interface should minimize training requirements for managers, administrators, and possibly operators. OSF-MOTIF is a standard user interface employed in many of the systems developed in a UNIX or POSIX environment. Availability of personnel capable of maintaining code based on the widely used interface defined by the OSF-MOTIF standard should make maintaining system software easier and less expensive.

"I do not believe that the DOTs should develop separate standards. ITS systems should be based on existing standards as much as possible."

Member of TxDOT's TransGuide Design Team

The use of the POSIX, ANSI C and OSF-MOTIF standards facilitated the development of software which is highly portable to various computing environments with minimal modifications. While it is nearly impossible to have a software application as complex as TransGuide which is 100% portable, programming utilizing the above standards will maximize the portability of the application developed. The importance of the portability of software has been demonstrated by many studies which have shown that reusing software is a technique which, if appropriately used, can drastically reduce the cost of software development efforts. Using these standards has increased the ease with which the TransGuide software can be reused in other similar applications.

The use of the CRAFT interface standard is specified for all communications equipment in the TransGuide system. The use of CRAFT will allow all communications system components to be controlled using a standard off-the-shelf network management system.

5.1.4 Redundancy and Fault Tolerance

Redundant Fiber Optic Connections

One of the primary goals of TransGuide system designers was that the system attain very high levels of reliability and availability. The importance of the system being up and operational a high percentage of the time led to a significant amount of redundancy and fault tolerance being designed into the system. Some of the types of redundancy and fault tolerance required by the system specification are listed in Table 5.1.4-1.

There is redundancy in TransGuide at the level of the field equipment, in the communications system, in the computer system at the TOC, and even in the implementation of the scenarios. The system as a whole also contains redundancy in, for example, the power sources.

The field equipment contains several levels of redundancy or fault tolerance. Most of the loop detectors in the freeway are initially arranged in a trap configuration, which consists of two loop detectors a known distance apart. If one of the loops fails, the system can still retrieve volume and occupancy data from the location. Much of the freeway system can be viewed via more than one camera. The VMS and the LCS are somewhat redundant to each other, and the information required to determine which lanes are open and which are closed is available to drivers via both LCSs and via the VMSs. Each LCS and VMS also has some built-in redundancy: if a single bulb is burned out, the sign or signal still displays the appropriate message. The LCSs and VMSs are designed to detect failed lamps and use operational lamps for those cases where a single lamp is normally used, and each also has redundant fibers to replace fibers that fail.

"The goal is to be up 99.9 percent of the time."

Member of TxDOT's TransGuide Design Team

The redundancy of the various links and pieces of equipment in the communications system is primarily related to the criticality of the equipment or link. Links that can affect the capability of the system to use several components were designed to be much more redundant and fault tolerant than those that only affect a single component. The communications links from the fiber hubs in the field are via redundant, separately routed fibers, and each of the redundant fibers is driven by a separate laser. The communications system contains redundant cards and channels at several levels. In the digital OC3 multiplexers in the fiber hubs and in the TOC, there are main and protect cards for each DS3 card and a spare DSl card for each seven active DSl cards. There are also spare timing cards in each of the OC3 multiplexers. The DS3 digital switch contains a spare DS3 card for each eight active DS3 cards. The DSl digital switch has redundant switching elements. The redundant capabilities are automatically engaged whenever an active element fails. Link failures and activation of redundant capabilities are reported to the Network Management System (NMS).

The PBX system was not specifically required to be fault tolerant. However, some phone lines connect the facility to the outside world without going through the PBX. Other, more fault tolerant communications capabilities will be added when critical dispatching services are transferred to the TOC.

The computer hardware system is fault tolerant and can continue to run through failures and maintenance. It consists of two independent com-

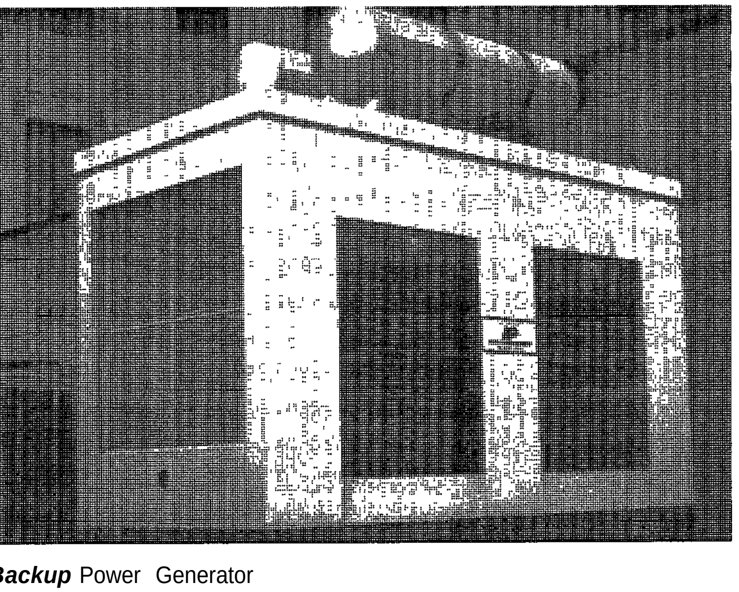
TABLE 5.1.4-1 - Levels of Redundancy

Component	Level of Redundancy	Comments
VMS	Two bulbs, 4% redundant fiber, each VMS is redundant to at least one gantry of LCS	Lamp failure detectors and automatic fail over are also used
LCS	Two bulbs per indication, 10 redundant fiber bundles per head, each LCS is redundant to another gantry of LCS and/or a VMS	Lamp failure detectors and automatic fail. over are also used
LCS/VMS to fiber hub	None	Each sign is redundant to others, but one sign could be lost
Fiber hub	Power - UPS backup, DS1 cards - 1 redundant card per up to 7 cards, DS3 cards - redundant card for each card, OC3 - redundant lasers with automatic switching	Could lose a significant amount of equipment if an entire fiber hub goes down
Fiber Hub to OCC communications	The main and protect fiber cables between the fiber hub and the OCC are routed separately. Extra fibers are available in the system.	Currently fiber is routed on each side of the freeway, In the future, fiber will be routed on completely different freeways.
OC3 multiplexer	OC3 - separate main and protect lasers, DS3 - separate redundant cards, Timing - separate redundant cards, DS1 - separate card containing 4 spare DS1 - channels for each 7 4-channel cards used in the cabinet	
Digital loop carrier	None	
DACS III, DS3 switch	One redundant card per 8 DS3 cards	
DACS II, DSl switch	Redundant switching elements	
Difinity PBX	None internal, however three lines do not go through the PBX and emergency dispatch is expected to provide additional capabilities	
DECserver 700 terminal controllers	None	
“AN	Dual ethernet networks, ports to both ethernets from each zone of the computer system	Half of the workstations will be lost if an ethernet network goes down, but half of them will remain up. Half of the terminal servers will also be lost.
Computer	Hardware fault tolerant computer, disk storage volume shadowing and multiple ports	On-tine repairable computing system, on-line replaceable disk and tape drives, Separate I/O ports
Cameras	Much of the freeway can be seen by a second camera	Varies depending on roadway geometries
OCC Power	On-line Power, UPS and Back-up generator	
Datakit virtual circuit switch	Currently contains a redundant processing element	Changes in the mission of the switch may indicate a reduction in required redundancy

puters executing the same instructions at the same time. There is a separate backplane from each of the computers to the I/O. If either of the computers fails, the other computer can **continue** operating the system without any reduction in performance. The operational computer can continue to be used as the failed computer is repaired or replaced. The LAN, used to communicate between the computer and the workstations, consists of dual segments allowing at least half of the workstations to continue operating if one of the LANs or LAN cards fails. Many of the potential failure modes will not result in any decrease in workstation use, since either of the computers can control access to either of the LAN segments.

The scenarios used to operate the TransGuide system have also been defined with redundancy and fault tolerance in mind. Multiple LCSs will be used for each incident so that if one fails, the message will still get through. LCSs and VMSs will also be used in concert to ensure that information gets to drivers.

The power for the TransGuide TOC is supplied by an Uninterruptable Power Supply (UPS) and a back-up generator. The system component failures that could substantially affect TransGuide operation are covered by some form of redundancy or fault tolerance.



***Backup** Power Generator

5.2 Incident Detection

The incident detectors used in the TransGuide ITS are standard buried loop detectors. The loop detectors are read by the LCUs, which are polled periodically by the computer system. The data generated by the loop detectors is used by TransGuide to generate alarms. Figure 5.2-l illustrates the typical interfaces between the loop detectors and the communications system.

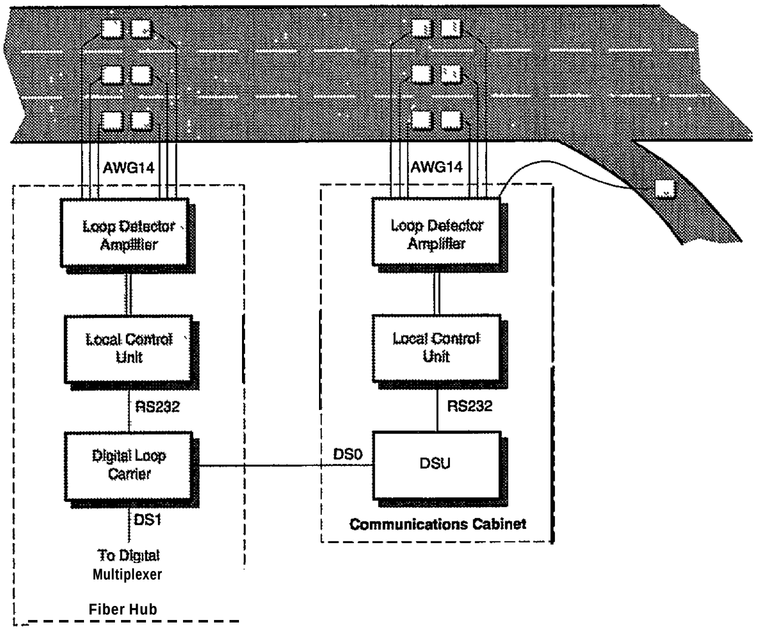


Figure 5.2-l - Typical Loop Defector Interfaces

5.2.1 *Loop Detectors*

Loop detectors were chosen as the method of detecting incidents based on several factors. One significant factor is the climate in San Antonio, which is relatively amenable to buried detection technology. There are essentially no extended periods of time when the ground freezes. There is also very little snow and therefore no salt is used on the roadways. An additional factor is that loops were already included in some of the existing freeways when they were constructed. Finally, loop detection technology is a well understood and mature detection technology. While other detection technologies may be applied in the future, the initial sections of the TransGuide ITS are being implemented using loop detectors.

Other detection technologies available include radar detection, visual or video detection, and audio based detection. Each of these technologies is being used in experimental or operational systems. However, none is as mature as the loop detector and none was demonstrably better or cheaper than loop detector technology when the TransGuide system was specified. A comparison of the various detection technologies is shown in Table 5.2.1-1.

While loop detectors may be susceptible to reliability problems in some locations, they are well suited to the San Antonio climate. Radar detectors are being experimented with in other cities; however, they do not offer specific information on separate vehicles. Radar detectors also require overhead installation, which may increase installation and maintenance costs. Video detection methods are beginning to be available, but they are relatively expensive and may suffer from some accuracy problems in specific vehicle or environmental conditions. Audio detection methods are also being developed, but they don't offer specific information on every vehicle and lack a performance history.

Loop detectors are buried in pairs approximately every l/2 mile along the main lanes of the freeway, although freeway geometry causes this spacing to be less in some sections. Table 5.2.1-2 illustrates the characteristics of various loop detector placement strategies. Isolated loop detectors are also buried at strategically located positions, such as on and off ramps. The single loop detectors can determine the count of vehicles passing over the detectors (volume) and the percentage of time a vehicle is over the sensor (occupancy). In addition to volume and occupancy, pairs of loop detectors can be used to determine the average speed of vehicles passing over the loops.

The loop detectors consist of six foot by six foot loops buried one inch under the roadway, The loops are constructed using one 14 gage (AWG) conductor. Loop pairs are installed 12 feet apart and are made up of differing numbers of

TABLE 5.2.1-l - Detection Method Decision Matrix

Characteristic	Priority	Loop Detection	Radar Detection	Video Detection	Audio Detection
Maintainability	Very high	High, stable soils, no salt usage, no ground freezing	High easily accessible	High, easily accessible	High, easily accessible
Reliability	Very high	High, (in San Antonio) stable soils, no salt usage, no ground freezing	Moderately high, little history, but no foreseeable high failure components	Moderate, Could have weather or vehicle specific detection problems	Moderate, little history, but no major expectation of failures
Initial costs	Medium	Medium, some loops already installed, lots of experience	Moderately high, new method, higher risk	High, expensive systems, prices should fall	Moderately high, new system, high risk
Operational costs	High,	Low, few failures, low maintenance	Moderate, components could be expensive	Moderate, components could be expensive, system updates may be required	Low, unknown, but no major expected expenses
Accuracy	High	High, lots of experience	Medium, should be good, but not much history	Medium, relatively complex and new	Medium, primarily unknown, could be relatively low
Ease of integration	Medium	High, some loops already available	Medium, requires overhead installation at all locations, could be fairly compatible	Medium, complex, overhead installation required at each location, but could be relatively compatible	Medium, installation new, compatibility unknown
Feasibility	Very high	High, available, known technology	Low, not well proven at design time	Moderate, available, but not well proven at design time	Moderate, not well proven at design time

TABLE 5.2.1-2 - Detector Spacing Decision Matrix

Characteristic	Priority	1/4 Mile	1/2 Mile	3/4 Mile
Detection accuracy	Very high	Very high	High	Moderate
Detection time	Very high	Very short	Short	Moderate
Installation costs	High	Very high	High	Moderate
Operational and maintenance cost	Moderate	High	Moderate	low

turns to minimize crosstalk. Changes in a loop's inductance are detected to sense the presence of a vehicle.

The loop detector signals are analyzed by LCUs similar to those used in traffic lights. The LCUs use the loop detector signals to determine volume and occupancy and (for dual loop configurations) speed. The LCUs also continually check the loops for long stretches of continuous presence or complete lack of presence, which may indicate loop detector problems. Problems are reported to the mainframe computer at the TOC and can result in reconfiguration of the loops.

5.2.2 Detection Algorithm

Various algorithms have been used to detect incidents in systems based on loop detectors. Many of the algorithms are flexible in some ways and each has advantages and disadvantages. The designers of the TransGuide system have designed the system so that the data necessary for several of the available algorithms is being collected. The system was also designed so the specific algorithm being used to detect an incident could be investigated using real-time data and, if desired, could easily be changed.

The selection of an initial incident detection algorithm focused specifically on the ability of the algorithm to rapidly detect incidents, even at the risk of a relatively high level of false alarms. The capability of the TransGuide system to verify incidents via the video subsystem is another reason that rapid detection of incidents has a higher priority than making sure that each alarm is actually an incident. Since the video subsystem is used for classifying incidents, there is also no requirement for the selected algorithm to classify the incidents. It is sufficient for the algorithm to detect the incident.

The algorithm used to generate alarms is flexible and can be tuned to trade off detection time nd false alarm rate. The computer polls each LCU on a periodic basis – the period of the poll defaults to 20 seconds, but can range from 10 to 60 seconds in 10 second increments. The computer generates an alarm based on a moving average of speed or occupancy – the period of the moving average can range from one to 10 minutes, but defaults to two minutes. The moving average is compared with a threshold, which can be a default value or a defined value. Thresholds can be defined for detectors based on the specific time of day, specific day of the week, or specific day of the year.

For each detector or set of detectors, there are up to four thresholds at which alarms are generated. A minor alarm will be generated when the average speed is less than the speed minor alarm threshold. The speed minor alarm threshold defaults to 45 mph. A minor alarm will also be generated if the occupancy is greater than the occupancy minor alarm threshold, which defaults to 25 percent. A major alarm will be generated when the speed is less than the speed major alarm threshold, which defaults to 30 mph. A major alarm will also be generated if the occupancy is more than the occupancy major alarm threshold, with a default of 35 percent. These thresholds can be adjusted at 15-minture intervals to values derived from historical data.

The algorithm described is expected to provide flexible, rapid detection of traffic incidents. An analysis being conducted as a separate part of the current operational test includes additional work on optimizing the detection algorithm. This analysis will also consider properties and capabilities of other existing algorithms.

5.3 Video as Incident and Message Verification

Once an alarm has been generated, the TransGuide video facilities will be used to verify and characterize the incident and to drive the dispatch of any necessary emergency services. The video ca-

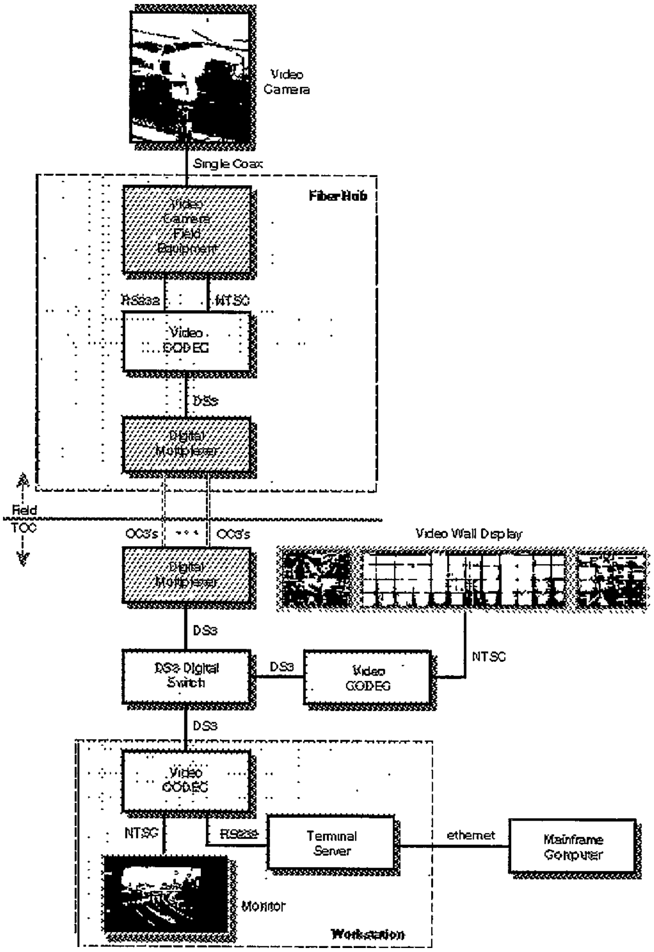


Figure 5.3-1 Video Interfaces

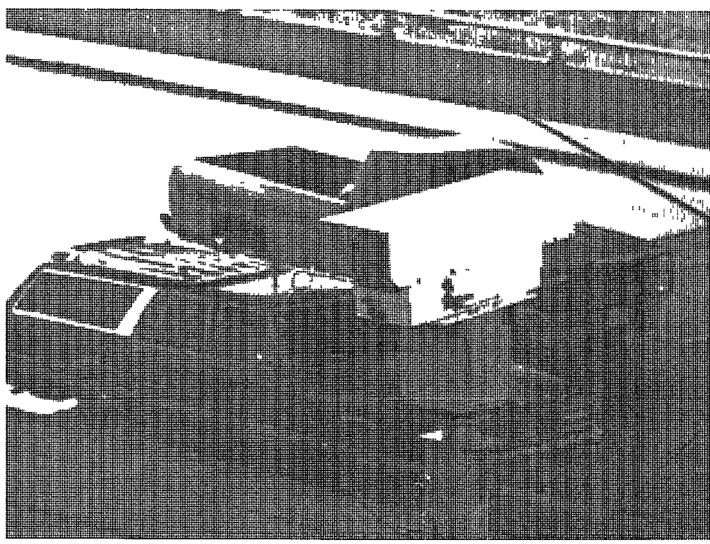
pabilities of the system are based on a user controllable camera and lens system, which is used by the operators to view the scene of the incident. The video signal generated by the camera is converted for communications to the control center by video codecs. The video signal is reconverted and displayed on CRT screens at the workstations or on arrays of screens making up the video wall in the control room. Figure 5.3-l illustrates how the video signal is collected by the camera and transmitted through the communications system to the workstation video monitors and to the video wall.

The video system can provide the operators with a color, detailed view of an incident in daylight or at night. Multiple operators, for example police and VIA dispatchers, as well as TxDOT operators, can access a view of the scene simultaneously. The use of the system's video capabilities is fundamental to the successful operation of TransGuide. Several combinations of cameras, lens systems, codecs, monitors, and video display units were investigated by TxDOT. The subsystems selected satisfy the demanding video requirements of the TransGuide ITS.

5.3.1 Cameras

The selection of the camera, the lens, and the spacing between the cameras involved several interrelated factors. A very powerful lens system could meet the video requirements with much wider camera spacing than a less powerful lens system. The more expensive cameras provide remote capabilities that allow the operators to make better use of more powerful lens systems. There are tradeoffs between the initial expense of the cameras and the initial expense of the additional communications system equipment required for less expensive cameras as well as tradeoffs between higher installation and maintenance and cameras with higher initial costs.

Table 5.3.1-1 contains a list of several types of cameras that were investigated along with some of their advantages and disadvantages. Cameras investigated included one-chip low resolution cameras, one-chip high resolution cameras, three-chip high resolution cameras, and digital cameras. The three-chip color cameras selected provide the good color and resolution needed. The highest resolution digital color cameras did not make a noticeable difference in the useable quality of the picture compared to the associated increase in



Remotely Controlled Camera

TABLE 5.3.1-l - Camera Technology Decision Matrix

Characteristic	Priority	Black & White	Low Resolution Single-Chip Color	High Resolution Single-Chip Color	Three-Chip Color	Digital
Color	High	NO	Yes	Yes	Yes	Yes
Daylight resolution	High	Moderate, loss of color clues	low, combined camera and tens	High, requires reasonable lens	Very high, combined with very good lens	Very high, but can be lost **quickly due to digital** magnification
Night resolution	High	High, good **contrast,** but some light artifacts	very low, divided light & low resolution	**Medium, divided** light, but high resolution	High, divided light, but high gain and high resolution	High, lost quickly when digital magnification is applied
Cost	High	low, low cost camera, variable cost lens	Low, tow cost camera and lens	Medium, medium priced camera relatively low cost lens	Medium high, moderately high priced camera,high priced lens	Medium, moderately high priced camera with fixed lens
Bright light effects	Moderately high	High, significant effects	Very high, combination of low resolution and large effects	High, some effects reduced	Medium, most effects reduced and some eliminated	Medium, most effects reduced and some eliminated

costs. They also lose some effectiveness when digital magnification is used. The lower resolution and less expensive cameras provide noticeably less useful video to the operator.

The camera technology selected was the three-chip, 1/2-inch, high-resolution color Charged Coupled Device (CCD) Frame Interline Transfer (FIT) camera. Most of the controls on the camera are controllable via an KS-232 interface, a standard serial digital interface used to communicate between devices. The user can control the gain and iris, as well as less frequently used characteristics including various pedestal levels, shutter speeds, black and white balancing and the DTL level. The one major characteristic for which remote control was not specified is the filter. A 5600K filter was manually selected on each camera as it was installed. The specifications required that the camera use at least 772 pixels horizontally and 492 pixels vertically to provide NTSC video with a minimum of 650 lines of horizontal resolution. The specifications required a wide range of gain settings (-3,0, 3,6,9,15, and 18dB) to allow the camera to work well in many lighting conditions, including near dark. The FIT three-chip set eliminates many of the streaking effects seen in the Interline Transfer (IT) chips used in some other cameras. The camera selected meets these specifications and is capable of providing high resolution, color video signals of good quality in most traffic control and emergency response situations. It provides 750 lines of horizontal resolution with a 60 dB signal-to-noise ratio.

5.3.2 *Lenses*

The selection of the lens system for TransGuide was an integral part of the video equipment selection process. Camera spacing versus lens magnification was one of the primary tradeoffs analyzed in the selection of a lens system.

Table 5.3.2-l lists alternative camera spacing and the implications of different spacing. Spacings of l/2 mile, 3/4 mile and 1 mile are illustrated. The camera/lens configurations were required to provide clear video of incidents at the resulting ranges of l/4 mile, 3/8 mile and l/2 mile. The number of cameras required at each spacing was also considered. The results of the investigation led to a choice of l-mile (nominal) spacing for the cameras. The availability of a lens stack and camera consisting primarily of off-the-shelf components, which could provide useable video at l/2 mile, was a prime determining factor in the selection of that spacing.

TABLE 5.3.2-l - Camera Spacing Decision Matrix

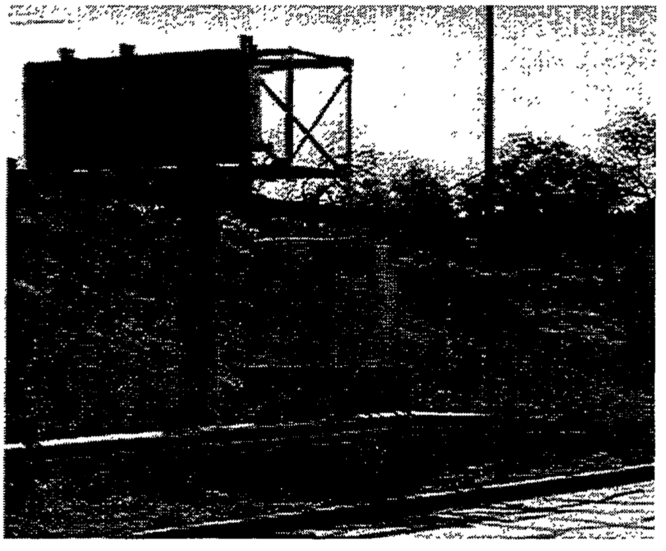
Characteristic	Priority	*1/2* Mile	*3/4* Mile	1 Mile	Comments
Installation costs	Very high	Very high, costs far exceed additional lens modification costs	High, requires modified lenses and additional cameras	Moderate, minimum overall initial costs	One mile typical spacing selected with some spaced closer due to road geometry
View detail	Very high	Very high, good detail {allows police dispatch) with relatively standard lenses	Very high/high, Requires modified lens to get good enough resofution to provide emergency dispatch, view of traffic only with standard lens	Very high/moderate, requires modified lens to provide detail required for police dispatch, difficult to view traffic with standard lens	Project goals required camera spacing/lens combination to provide sufficient detail for Police to dispatch emergency services
Coverage	High	Very high, almost 100% coverage without any obstructions	High, almost 99% coverage with very few obstructions	High, almost 98% coverage with few obstructions	Avoiding obstructions caused some variations in selected spacing
Maintenance and operational cost	Medium	Very high, additional camera and equipment required	High, Some additional equipment required	Moderate, minimum of additional equipment required	

Once the camera spacing was determined, the selection of the lens system necessary to meet the TransGuide requirements at that spacing could be made. Table 5.3.2-2 lists the lens magnifications investigated and the characteristics of the video available at l/2 mile with the various lens configurations. The lenses specified for the TransGuide video system are made up of several components, including a standard 2/3-inch lens capable of being remotely zoomed from 9.5 to 15. An adapter, required to allow the 2/3-inch lens to interface with the l/2-inch camera lens mount, provides an effective magnification of approximately 1.48. A teleconverter with a magnification of 1.5 and an additional extender lens with a magnification of 2.0 are also specified as part of the lens system. The specifications require that the extender be capable of being remotely added to or taken out of the lens configuration. Overall, the specified lens system is capable of providing a magnification of between 21 and 33.3 without the

TABLE 5.3.2-Z - Camera Lens Decision Matrix

Characteristic	Priority	15:1 Zoom *	30:1 Zoom *	50:1 Zoom *
Emergency se rv-ices identification	Very high	Low, vehicle can be seen, but almost no information could be used to accurately dispatch emergency services	Moderate, vehicles and people can be easily seen, but fuel spills, smoke, hazard plackards and extent of injury cannot be seen	Very high, detailed information such as fuel spills, smoke, hazard plackards and extent of injury can be easily identified
Vehicle Identification	Very high	Moderate, open lanes can be identified	High, vehicles can be identified	Very high, vehicles can be easily identified
Initial cost	High	Low, inexpensive, standard lens configuration	Medium, relatively inexpensive if modified with extenders	Medium, relatively inexpensive if modified with tele-converters and extenders
Maintenance	High	Low, standard lenses	Medium, slightly modified, standard lenses	Medium, slightly modified standard lenses

*All characteristics are described for 1 -mile camera spacing (1 /2-mile view)



Variable Message Sign (VMS) with the Default, Blank Message

extender and between 42 and 46.6 with the extender in place.

The requirement for remote control of the extender lens is due to the effect of the extender on the light available to the camera. While the other lenses and components listed above do not appreciably reduce the amount of light available to the camera, the extender does. The extender must be remotely controllable to provide both the magnification needed at the maximum distance and the necessary light gathering capability. Required for those situations where fine detail or maximum distance viewing is needed, the extender must be removable so the video system can provide useable video in the lowest light conditions.

"The system is designed to provide police and fire with the tools needed to dispatch emergency services within two minutes."

Member of TxDOT's TransGuide Design Team

5.3.3 Pan and Tilt Unit

The operator must be able to control the orientation of the camera to direct it at a potential traffic incident; therefore, a remotely controllable pan and tilt unit was specified for each of the cameras in the TransGuide ITS. The pan and tilt unit, as specified, must be designed to operate in the environment expected for equipment mounted above the freeway. It must also allow the camera to be pointed in almost any direction to provide unrestricted coverage of traffic incidents.

The specifications for the TransGuide system require a unit capable of spanning 350 degrees horizontally and from 30 degrees above horizontal to 90 degrees below horizontal (straight down). The pan and tilt unit is controlled by the operators using the same screen interface used to control the camera's focus and zoom.

5.3.4 Video Codecs

For systems using digital communications for the video signal, video codecs provide the interface between the video subsystem and the communications subsystem (both at the camera end and on the video display end). The video codec must be compatible with the video signal and capable of converting the signal to and from the form used by the communications system without significant loss of clarity.

There are several methods of interconnecting the field and TOC portions of the video system. The cameras in the field could have been hard wired to specific monitors in the TOC using direct analog communications. The signals from the cameras could have been frequency division multiplexed onto a single coax line in the same way multiple video signals are multiplexed onto the cable TV lines coming into our houses. Alternatively, the camera video signals could also be converted by a codec into digital signals. The digital signals could then be transmitted via a digital communications system to the TOC, where the digital communications system could be used to distribute the signals to codecs for reconversion to analog form for distribution to monitors and other video display devices.

The use of codecs presents both advantages and disadvantages. One benefit is that equipment requirements can be minimized by placing the codecs at the TOC after the switches. However, since there are no standards for video codecs, placing the codecs after the switches has the disadvantage of locking the whole system, even cameras not yet purchased, into using the same codec so the signals will be compatible. The DS3 codecs selected, however, are upgradeable to future video transmission standards. Based on the advantages of a digital video signal and advantages in the

TABLE 5.3.4-l - Video Codec Decision Matrix

Characteristic	Priority	56 K Baud	t.5 M Baud	2x 1.5 M baud	45 M Baud	135 M Baud
Maintainabitity	Very high	Moderate, standard phone line, but significant compression hardware	Moderate, standard medium speed phone lines and compression hardware	Moderately low, two medium speedphone lines and compression hardware	High, one standard high speed phone line and a little compression hardware	Moderately high, one very high speedphone line and very little compression
Reliability	Very high	Moderate, standard equipment, but significant compression	Medium, no significant problem areas	Moderately, multiple com-munications lines needed, but fess compression	High, standard equipment and network management	High, standard equipment and network management
Video clarity	High	Very low, very jumpy and not very good resolution	low, jumpy in dynamic situations	Moderately low, fairly good in stable situations, less resolution in dynamic situations	High, near broadcast quality	Very high, broadcast quality
Installation costs	Medium	Very high, expensive compression	High, fairly expensive compression equipment	High, more complex compression and communications equipment	Medium, standard communications equipment and inexpensive compression	Medium, high speed, but standard com-munications and relatively inexpensive compression

communications system (discussed later), digital transmission of the video signal using codecs was selected.

Codecs that operate at several different speeds were considered, some of which are listed in Table 5.3.4-1, along with relevant characteristics. Codecs generally range from modem speeds of 19.2 to 56 Kbps (about the fastest signals supportable over standard phone lines), to 135 Mbps (capable of transmitting broadcast quality video). Typical speeds include 56 Kbps (DSO), 1.544 Mbps (DSl), 44.736 Mbps (DS3) and 135 Mbps, as well as several intermediate combinations of speeds. The lower speed codecs tend to cost more, since significant, high speed computation is required to compress a video signal onto the lower speed signal. The quality of the video generally improves as the speed of the signal is increased. In particular, the quality of the video in dynamic situations is most dramatically affected by the increase in transmission speeds. Investigation of the available equipment showed that the motion artifacts and jumpiness of the video signals are disturbing and distracting in the systems with communications rates below 44.736 Mbps. Signals at 1.544 Mbps (the next lower widely available data rate) do not even handle still camera scenes without noticeable motion artifacts. Video signals resulting from moving cameras and transmitted over 1.544 Mbps links do not result in useable displays. The use of 1.544 Mbps transmission rates would severely affect the operators' effectiveness and the long term useability of the system. The investigation also revealed that the quality of the video signal transmitted at 44.736 Mbps is not significantly different (from a user perspective) from a signal transmitted at the 135 Mbps rate. After considering the factors listed above, a video signal transmission rate of 44.736 Mbps (DS3) was selected.

"We designed the communications system and the video system at the same time so they complement one another. The integrated design provides sufficient bandwidth that inexpensive codecs can be used. "

Member TxDOT's of TransGuide Design Team

In keeping with the coordinated design of the video and communications subsystems, the specified codec is required to convert NTSC signals generated by the camera into DS3 signals. The DS3 signals can then be multiplexed onto the OC3 signals used in the fiber optic communications from the field to the TOC. The codecs must also be capable of converting the DS3 signals back into NTSC video signals at the TOC.

One of the major advantages of using standard telecommunications equipment for the communications system is that it can be configured so that only one cddec will be required for each camera, monitor or video wall screen. System configurations in which the video is switched after it has been demodulated would require modulation and demodulation equipment for each camera. One codec each per display and camera requires more codecs initially, but it will require far fewer codecs in the long run. As the system expands, the number of cameras will far surpass the number of displays. Modulation and demodulation equipment for each camera requires more equipment than one codec for each camera and one for each display.

The video codecs are also required to provide two bidirectional serial control channels (RS-232 compatible at up to 19.2 Kbaud) for camera control functions. One of these lines is used to drive the camera controls, the lens controls and the pan and tilt unit controls. All of these functions are controlled via a single camera control unit. The camera control unit is mounted on the camera itself. The second RS-232 channel is available for future requirements.

The system specifications also placed specific requirements on the codecs to aid the NMS in system maintenance. The codecs are required to provide contact closure alarms for incoming and outgoing signals, as well as power supply failures. Dual power supplies are also required on each rack of codecs.

5.3.5 *Monitors*

Each of the operator workstations has four color CRT monitors for viewing video from the cameras. Each of the monitors is required to have a 13-inch screen, be RGB, and NTSC compatible, and be mountable in a standard 19-inch rack. The

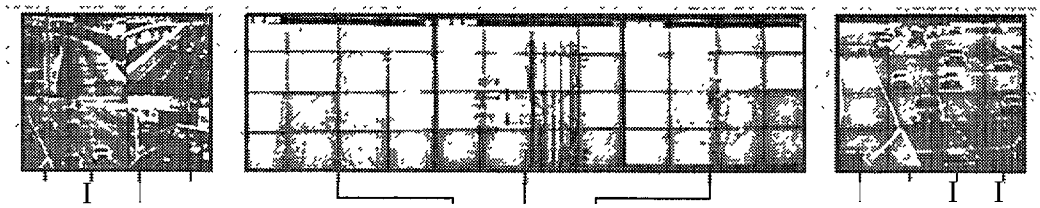
Workstation Screen with City Map and Camera Control **Screen**

monitors must have a resolution of at least 700 horizontal lines.

Nine-inch and 15-inch monitors were also considered. The 13-inch screen was chosen to minimize operator head movement when switching from the 19-inch workstation monitor screen to the four video screens. Experiments were conducted to evaluate the effects of various screen sizes, based on the expected content of the two types of screens used in a workstation. The experiments were conducted to determine the most comfortable viewing based on the different screen sizes. The results of the investigation indicated that the 13-inch screen was the most suitable size.

The specifications for the CRT monitors are quite specific. An auto setup capability and specific CRT protection capabilities are required. Requirements for aperture correction, filters, modes of operation, pitch chromaticity coordinates, color temperature, color temperature stability, brightness range, maximum brightness and contrast are included. Degaussing functionality and a specified warm-up period are required, as are specific raster and picture performance parameters (e.g., normal and underscan adjustments, stability of raster size, and linearity of center horizontal and vertical lines). Input connectors for power, video and control inputs; NTSC and RGB performance; and synchronization are also specified. Environmental specifications include temperature, x-ray, electromagnetic compatibility and safety considerations, and the capability to withstand external power fluxuations.

5.3.6 Video Wall



TOC Control Room Video Wall

A video wall capable of being used to display maps and video to personnel in the control room and to observation rooms adjacent to the control room was required in the procurement specification. The specification originally required two types of rear projection video equipment; however, during the final design and implementation of the system, a better product became available. The improved product consists of a matrix of rear projection screens with thin borders around each screen. The thin bordered design has brightness and clarity advantages over the large rear screen projectors specified. The matrix of screens was substituted for both types of rear screen projection systems specified. Figure 5.3.6-l depicts the video wall and illustrates the interconnections between the video wall and the rest of the TransGuide system.

The video wall consists of three separate panels. The center panel consists of a twelve by four matrix of 40 inch diagonal screens. On each side of the central panel is a panel consisting of a four by four matrix of 40 inch diagonal screens. Each of the two outer panels is connected to four codecs. The system is capable of displaying from one to four separate video displays on each of the two outside panels. A single video signal can cover the entire panel, or parts of the screen can display separate video images. The central panel consists of 48 screens in three side-by-side arrays of 16 screens and is driven by a system similar to those used by the operators. The central panel can display up to three workstation screen images, including active maps of portions of the freeway system. The displayed maps are updated by the system in real time.

The video wall panels allow the managers to make video available to the room at large. Pertinent video can be directed to the video wall, where all of the operators, as well as observers located in adjacent rooms, can simultaneously see the displayed images. To clarify real-time conditions on the freeways, a manager can also make critical sections of maps available to operators and observers by displaying them on the central panel.

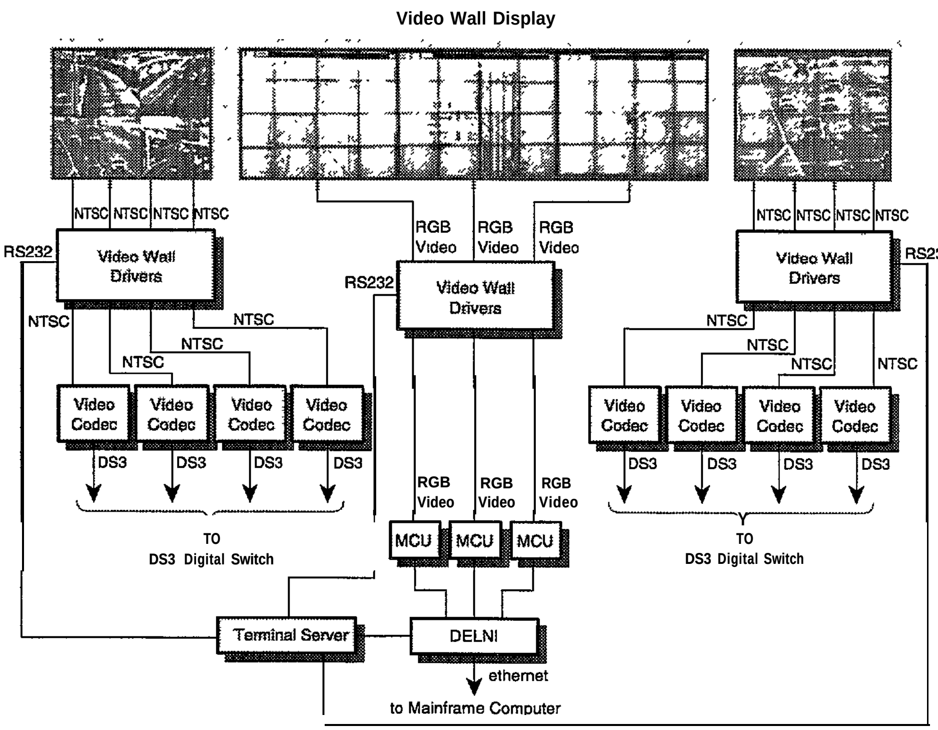
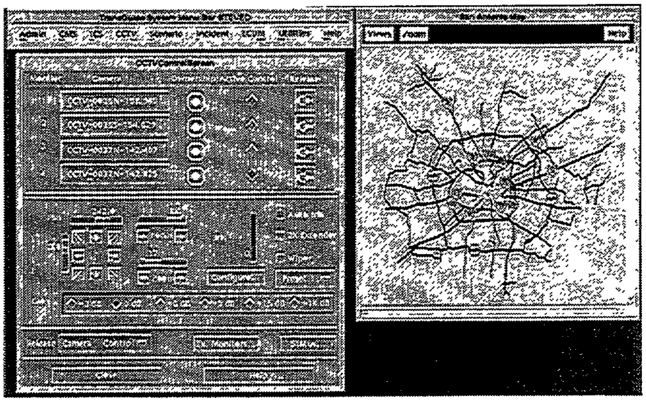


Figure 5.3.6-l - Video Wall

5.3.7 ***user Control Functions***

The system allows operators to control any of the video equipment needed to appropriately respond to incidents. Each operator can select up to



four cameras to view or view and control (only one operator can control a given camera at one time, however). If camera control is selected then the operator can control the direction that the camera is pointing via pan and tilt functions. The operator controls the tradeoffs between the area of view and the detail in the video display by using the zoom function and by enabling or disabling the two times (2X) extender. The operator also controls the focus of the camera and can allow the camera to provide some automatic control of the brightness of the picture using an automatic iris function. The brightness can be controlled manually by selecting the manual iris control function. The brightness of the picture, in addition to the field of view and amount of detail, is also affected by enabling or disabling the 2X extender. Additional brightness control is available to the operator by setting the gain level. All of these functions, as well as other camera functions that will not be used as frequently, are available to the operator from the workstation using a mouse based interface. These functions are also controllable using a laptop computer and a monitor temporarily attached to the video field equipment in the fiber hub specifically for troubleshooting.

Since the cameras are used for incident verification and characterization, it is critical that the operator be able to easily control the camera parameters that most directly affect the ability to determine the status of the incident. Parameters over which the operator has immediate, direct control include: the direction the camera is pointed, zoom, focus, iris, and gain. Once an operator has been assigned control of a camera, he or she has complete control over the remotely controllable camera functions, When an alarm occurs, control of a camera may be requested by and granted to a manager or operator. When control of a camera is granted, the system will set the camera up with a set of parameters based on the location of the alarm. Those parameters are selected to minimize the time required to evaluate the incident. When control of the camera is passed to the manager or operator, the camera should be pointed in the correct general direction for the incident, with approximately correct zoom and focus.

5.4 Communications System

The communications system ties all of the other pieces of equipment in the system together. One of the basic attributes of a traffic information system is its geographically dispersed nature. The sensors used for detection, verification and characterization of incidents must be distributed throughout the road system, and the information produced by the traffic management center must be distributed to the drivers on the roads to be useful. There must be a system for collecting the raw data used to generate traffic information and for disseminating that information to the drivers.

Several architectures were considered as the basis of the TransGuide system. Some of the architectures consist of a single physical medium. Others contain a variety of media. The selection of the architecture, the physical media and the mechanism for switching the control and video was based on the fact that those attributes are interrelated.

5.4.1 Communications System Architecture

Several different types of communications system architectures are used in traffic control systems, and several were investigated as part of the specification task for the TransGuide system. Primary considerations included the system maintainability (including the availability of network management capabilities), equipment requirements, environmental requirements, reliability and supportability.

Factors investigated included the overall architectures, the level of performance, and the impact of funding mechanisms. Some of the variations considered are listed in Table 5.4.1-1, along with comments on the characteristics considered.

Traffic control systems frequently contain several types of communications media; one to han-

TABLE 5.4. I-1 - Communications System Decision Matrix

Characteristic	Priority	Leased T1	Leased T3	Dedicated optical, coax, and digital	Microwave	Dedicated SONET fiber (OC3 Multiplexer)
Maintainability	Very high	High, single telco connection, external network management	High, single telco connection, external network management	Low, multiple cables,no standard network management	Low, many independent connections required	High, one cable,standard network management
Reliability	Very high	Medium, not under direct control	Medium, not under direct control	Low, multiple failure points	Low, weather and interference among other factors	High, redundant fiber and com-munications cards
Operational costs	High	Moderately high, leasing costs add to operational costs	High, leasing costs for T3 connections are very high	High, maintenance will increase overall operational costs	Medium, easy access for all maintenance requirements	Low, redundant fibers make maintenance non-critical operation
Maximum data rate	High	1.5 Mbps	4.5 Mbps	Varies, anatog, low speed data and fiber for future applications	4.5 Mbps	155 Mbps per fiber
Video clarity	High	Medium, jumpy in dynamic situations	High, near broadcast quality	High, standard cable type signals	Variable	High, near broadcast quality
Installation costs	Medium	Low, telco investment	Low, telco investment	Medium, cables must be pulled	Medium, establish path for each hub	Medium, must pull fiber
Video interface costs	Medium	High, compression required	Low, very little compression required	Very low, standard components	Very high	Low, very little compression required

dle the data and control functions, one to handle the video signals and another to handle future ITS applications. These systems typically contain a T1 network, a multimode fiber optic cable, and a single mode fiber optic cable. The Tl network is used for voice and data transmission, the multimode fiber optic cable is used for transmitting a modulated version of the analog video signal, and the single mode fiber optic cable is intended for future ITS requirements.

The use of three separate systems significantly increases the problems associated with managing the networks. There are no off-the-shelf network management systems available to manage three disparate networks. In fact, separate off-the-shelf network management systems capable of managing all three types of networks independently were not readily available while TxDOT was specifying the TransGuide system. The complexity of maintaining more than one type of network, and the additional cabling and connecting required for separate networks, exacerbates the management problem.

One communications system considered for distributing video signals included modulation and demodulation equipment for each camera, one on each end of the fiber optic cable. In this configuration, providing the video signal to any of the displays would require a large analog video switch capable of switching any one of the cameras (eventually up to 1500) to each of the displays in a non-blocking fashion. The system requirement to be able to view any camera on any of the CRTs (simultaneously, if desired) places this architecture at a severe disadvantage. A communications system in which each camera is hardwired to a specific CRT does not require a large analog switching capability. However, it does not meet the system requirements.

Another communications system choice would be to use frequency division multiplexing of the video signals onto a common set of cables. Initially, a single cable could handle all of the cameras, but eventually three to ten cables would be required, depending on the number of channels multiplexed onto each cable. This communications system would operate much like a CATV system, minimizing the overall amount of cable installed. It would also primarily use off-the-shelf components. However, some parts of the system would probably not be available off-the-shelf. The system would also require either separate data and voice networks or would require custom equipment to transmit voice and data signals over the cable.

The communications system eventually selected is illustrated in Figure 5.4.1-1. It includes the use of dual single mode fiber optic cables from fiber hubs located strategically throughout the system. The cables are separately routed. An automatic fail-over mechanism switches to the back-up cable in the event of a failure of the primary cable or drive laser. There are several significant advantages to this communications architecture. The digital fiber optic system is compatible with the use of Synchronous Optical Network (SONET), a telephone industry communications standard. The use of the same single mode fiber optic cable used by telephone companies and the use of SONET indicate that long-term support will be available. The selection of communications equipment used by telephone companies also means that there are off-the-shelf network management systems available to control the network, which means reduced maintenance costs and increased system reliability. The selection of the same fiber optic cable, interfaces, and protocols used by telephone companies also means that equipment is standard and available off-the-shelf as well.

The availability of environmentally hardened field equipment for this communications architecture also allowed system designers to minimize development of special equipment and operational

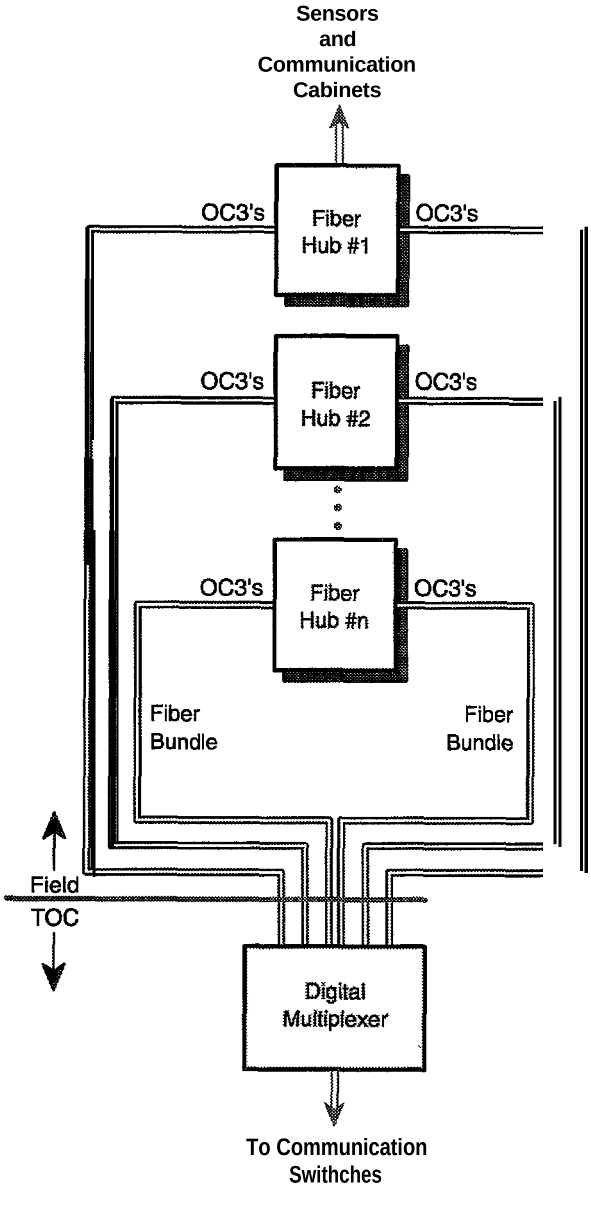


Figure 5.4. 1-1 - Communications Architecture

maintenance costs while maximizing the reliability of the system. One of the driving factors in the selection of the OC3 based communications system was the availability of environmentally hardened (primarily high temperature) equipment to perform the functions required in the fiber hubs. The fiber hubs must be located near the cameras themselves and are therefore geographically distributed. The use of equipment that is not environmentally hardened in non-environmentally controlled fiber hub cabinets is incongruent with the reliability and availability goals of the TransGuide system. If the communications system components required for the fiber hubs were not

TABLE 5.4. 1-2 - Communications Network Topology Decision Matrix

Characteristic	Priority	Multiple, Serial Rings	Star, with Redundancies
Maintainability	Very high	Moderate, requires higher capacity equipment, **which** requires temperature control	High, requires lower capacity equipment, available in temperature hardened versions
Reliability	Very hig h	High, designed as a redundant network	High, designed as a redundant network
Operational costs	High	Moderate, higher capacity equipment and temperature controls	Low, lower capacity, temperature hardened equipment
Installation costs	Medium	Moderately high, higher **capacity equipment** and temperature controls,but less fiber equipment and morerfibe	Moderately high, lower capacity temperature hardened

available in temperature hardened versions, the fiber hubs distributed throughout the city would have to be environmentally controlled, significantly increasing both the initial cost of the system and ongoing operation and maintenance costs.

Diversity can be provided in fiber optic systems by two different physical connection architectures. One architecture is defined as a ring and redundancy in a ring is based on multiple routes between nodes. A second architecture is defined as a star and redunancy in a star is based on route diversity. The selection of the best communications architecture for the TransGuide system was based on the unique attributes of the TransGuide communications system. Table 5.4.1-2 contains a list of communications architectures considered, along with some indication of the characteristics considered.

In the ring architecture, each node is connected to two other nodes to form a logical ring. Each node can communicate in either direction around the ring. Therefore, a ring configuration does not allow a single failure (such as a cut conduit) in any one place to isolate any node on the ring from any other node. Most telephone company systems are built using the ring architecture. A system based on the ring architecture require communications equipment at each node capable of handling all communications through that node. Each node in a telephone company communications system generally communicates in a statistically distributed manner to each of the other nodes in the system.

Random node-to-node communications are not a requirement of the TransGuide communications system. Each TransGuide node communicates only with the TOC node. In a ring architecture, all communications from each node would need to be capable of reaching the TOC node in either direction. Each node would require the ability to transmit all of the communications from most of the other nodes in the ring. To implement such a ring architecture in the TransGuide system, multiple rings would have had to be configured using OC24 or OC48 equipment in the fiber hubs. Neither OC24 nor OC48 equipment is available in environmentally hardened versions.

"Ring Configurations require carrying all signals either way. That would require . . . equipment . . . not available in temperature hardened versions. "

Member of TxDOT's TransGuide Design Team

The star architecture provides another way to deliver the diversity required for fault tolerance. In a star architecture, two fibers from each node are connected to the central facility via diverse routes. Designing the TransGuide communications system as a ring would have required placement of non-hardened or specially developed communications equipment in the field. Route diversity based on the star architecture was chosen over ring diversity based on multiple routes through the system.

Some communications systems used in ITS applications consist primarily of leased facilities. Both data and video are sometimes transmitted over Tl(l.544 Mbps) links. The advantage of using leased lines is that the DOT does not have to pay up front for the installation of the communications system or staff up for ongoing maintenance of the network. However, a major drawback of the leased systems is that they represent a significant ongoing operational cost. While the Tl circuits often used in leased systems are less expensive to lease than T3 circuits, they have severe disadvantages:

>They are not capable of transmitting the same quality of data.

>The Tl video codecs are more expensive.

*Much of the available equipment is not packaged for the environment it will face in the field.

The ability to minimize maintenance and operational costs and maximize reliability and availability by using a TxDOT owned, redundant system composed of standard off-the-shelf components and managed by an off-the-shelf, comprehensive network management system is ideal for the TransGuide system.

5.4.2 Fiber Optic Communications Network

Fiber Optic Hub

The fiber optic communications network of the TransGuide system is made up of several types of equipment. The signals to and from the equipment in the field are collected in fiber hubs, which communicate the data through the fiber cable to the TOC where it is distributed as required. An example of the interconnections between field equipment and the fiber hubs is illustrated in Figure 5.4.2-l. Multiple cameras or controller cabinets may be connected to the same fiber hub.

A fiber hub may contain an LCU and amplifiers for the associated loop detectors. It also may communicate via communications cabinets to LCUs, LCSs, VMSs, and traffic light controllers. The fiber hubs also contain a Telemetry Remote Unit (TRU), which is a device capable of providing alarm information to the NMS. The interfaces to all of the controllers and computer processors are based on RS-232. The interface to field phones (whether in the fiber hub or in connected field equipment such as a VMS or a CMS) is via standard DSO telephone interfaces (the same interfaces used by phones at home or work). The fiber hubs also communicate to the LCS and VMS controllers via standard RS-232 interfaces. However, since some controllers are not located in the fiber hubs, the communications are first converted to DSO by Data Service Units (DSUs) colocated with the controllers. The DSU, a digital modem connecting a computer or controller to a phone line, is capable of accepting RS-232 interfaces at standard rates ranging from 2,400 bits per second to 56,000 bits per second.

The RS-232 interfaces, the phones in the equipment boxes, and the DSO lines are multiplexed in the fiber hub by a digital loop carrier (specifically an SLC 5) onto DSl (1.544 Mbps) lines. Up to 24 RS-232 or DSO lines can be time division multiplexed into each DSl signal. Up to 48 DSO channels can be interfaced to the digital loop carrier in each fiber optic hub.

The fiber hubs also contain the video codecs and video field equipment that provide an interface to the cameras. The video codec can convert an analog NTSC video signal to a digital DS3 ***(4-4.736*** Mbps) line. The DSl and DS3 signals are multiplexed by an OC3 digital multiplexer (specifically a DDM 2000) in the fiber hubs onto the fiber optic cables at OC3 (155.52 Mbps) rates. There are dual transmit and receive fibers in each OC3 interface to the fiber hub.

As shown in Figure 5.4.1-1, fibers are routed through diverse routes from the fiber hubs to the TOC. Once in the TOC, as shown in Figure 5.4.2-2, the fibers enter the OC3 digital multiplexer (again

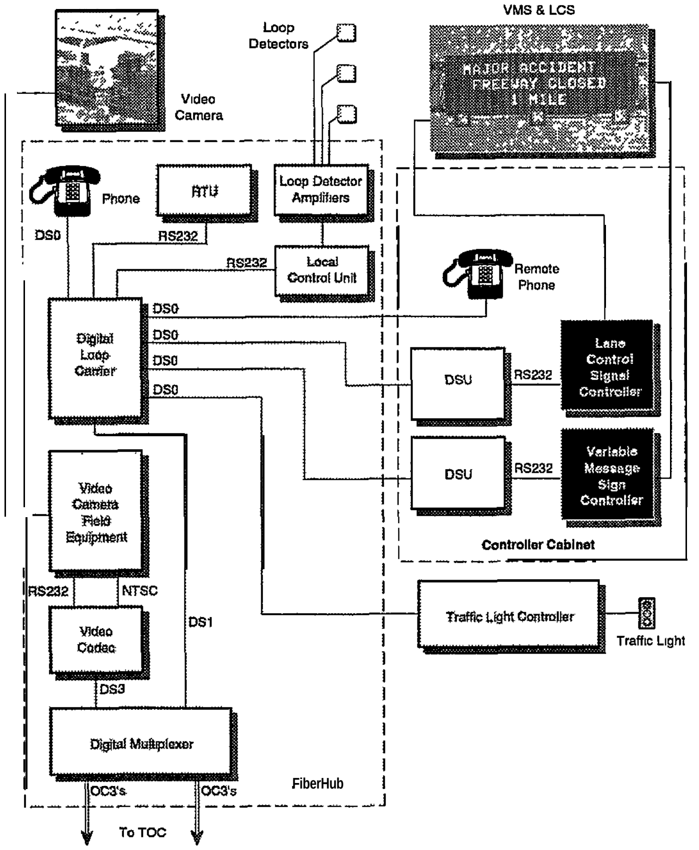


Figure 5.4.2-1 Fiber Optic Hub

a DDM 2000). In the OC3 digital multiplexer, the video links are reconverted to DS3 signals and the rest of the signals are converted back into DSl signals. The DS3 video signals are routed to the DACS 3 digital matrix switch, discussed in Section 5.4.3. The DSl signals are routed to a DACS 2 digital matrix switch, which demultiplexes the various voice and data signals from the fiber hub. The signals from the field equipment and the voice lines from the equipment boxes are collected into separate sets of DSl signals. The DSl signal containing the voice circuits is then connected to the digital PBX where they can be connected to phones internally or, through trunk lines, to phones external to the TOC. The DSl signals that carry data from the field equipment are passed to a digital loop carrier (specifically an SLC 5), which demultiplexes the DSl signals and sends control and data signals to terminal servers (specifically, a set of DECserver 700-16s), through which they can be interfaced to the computer system via the LAN.

5.4.3 Video Switching

As shown in Figure 5.4.2-2, once the video signals have been demultiplexed from the OC3 signals to the DS3 signals, they are transmitted to the DACS 3 digital matrix switch. The digital matrix switch is a 512-by-512 DS3 switch that can connect any of the video signals to any of the video codecs installed in the TOC. There is one video codec for each monitor in the workstations and four for each of the side video wall panels.

During the design of the system, several methods of handling the video distribution and video switching were investigated. If the video signals were transmitted in analog form, then an analog switch would have been required to distribute the video signals to the various monitors. Existing analog switches capable of handling the required video signals are expensive, large, and non-standard. Even with digital signals, conversion of the signals from digital to analog could have been done before or after the switch. Conversion of the signals before the switch would have required a separate codec in the TOC for each camera rather than for each monitor. In the initial implementation of the system, the difference in the nurnber of codecs would not have been large. However, as the number of cameras installed on the roads increases in proportion to the number of monitors, the difference would become very large. While the number of monitors to be supported is not expected to exceed 116, the number of cameras could exceed 1500. The method selected for switching the video among monitors was to use a standard telecommunications switch. The signals are switched before they are converted back to analog form.

One of the features of the off-the-shelf DACS 3 digital matrix switch is that only a limited number of cameras can be viewed at more than one monitor at a time. To be viewed by more than one monitor at a time, the camera-to-monitor connection must be set up as a conference call. The off-the-shelf DACS 3 is only capable of initiating 31 simultaneous conference calls. While a single conference call should allow all of the monitors to view a single camera, no more than 31 cameras can be viewed on more than one monitor at a time. In order to avoid this problem, the computer system software that controls the DACS 3 switch must specifically allocate and track the conference

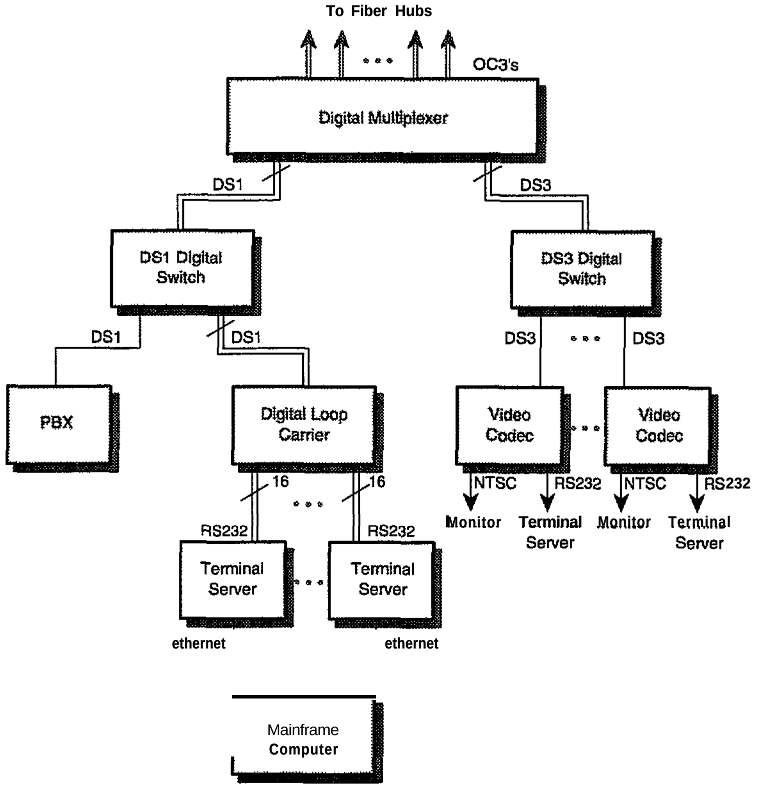


Figure 5.4.2-2 - TOC Communications

calls, so additional requests for camera access can be handled appropriately,

5.4.4 Digital Communications Switching

Original TransGuide system specifications required that the data signals used to collect data from and control the field equipment be connected to the computer via a virtual circuit switch (also known as a Datakit). However, during system integration, it was determined that the virtual circuit switch was not capable of making and breaking the nu.tnber of virtual circuits at the speed required for the system to operate as specified. The virtual circuit switch is intended for switching telephone calls, and part of the protocol involved in switching telephone calls is a two-second delay between a phone hanging up and the phone line being released. The reason for this delay is that a short disconnect or flash-hook is used to signal the switch for some services. For example, phones with call waiting can use the flash-hook to switch between two calls. Since the virtual circuit switch follows standard telephone conventions, it will not break a circuit without waiting to see whether the interruption is a signal or is truly the end of the call. The original TransGuide specifications were written with the understanding that the virtual circuit switch could switch between lines fast enough to allow the computer to poll all of the field equipment every 10 seconds. With hundreds of pieces of field equipment and switching times longer than one second per piece of equipment, the virtual circuit switch proved to be incapable of providing the required level of switching for some equipment. The switch was therefore replaced by the terminal servers discussed below for interconnecting the computer mainframe with most of the field equipment.

The virtual circuit switch is still used to interconnect the NMS with the various pieces of communications equipment in the TOC, as well as to some of the TRUs in the field. The polling conducted by the NMS does not require the high speed switching required by the polling conducted by the mainframe computer. The virtual circuit switch allows the NMS to interface with the many pieces of communications equipment that it must track with a limited number of RS-232 ports.

5.4.5 Network Management System (NMS)

One of the primary reasons for selecting the communications components used in the TransGuide communications network, especially the DS3 and OC3 level communications and the SONET compliant equipment, was the availability of off-the-shelf network management capabilities. Standard telephone company communications equipment is compatible with local and remote alarm sensing capabilities, as well as interfaces that facilitate provisioning, maintenance, configuration management, administration, and performance management. The TransGuide system includes an off-the-shelf NMS that uses those interfaces, to provide centralized management of the entire TransGuide communications system. The interconnections that facilitate network management are illustrated in Figure 5.4.5-l.

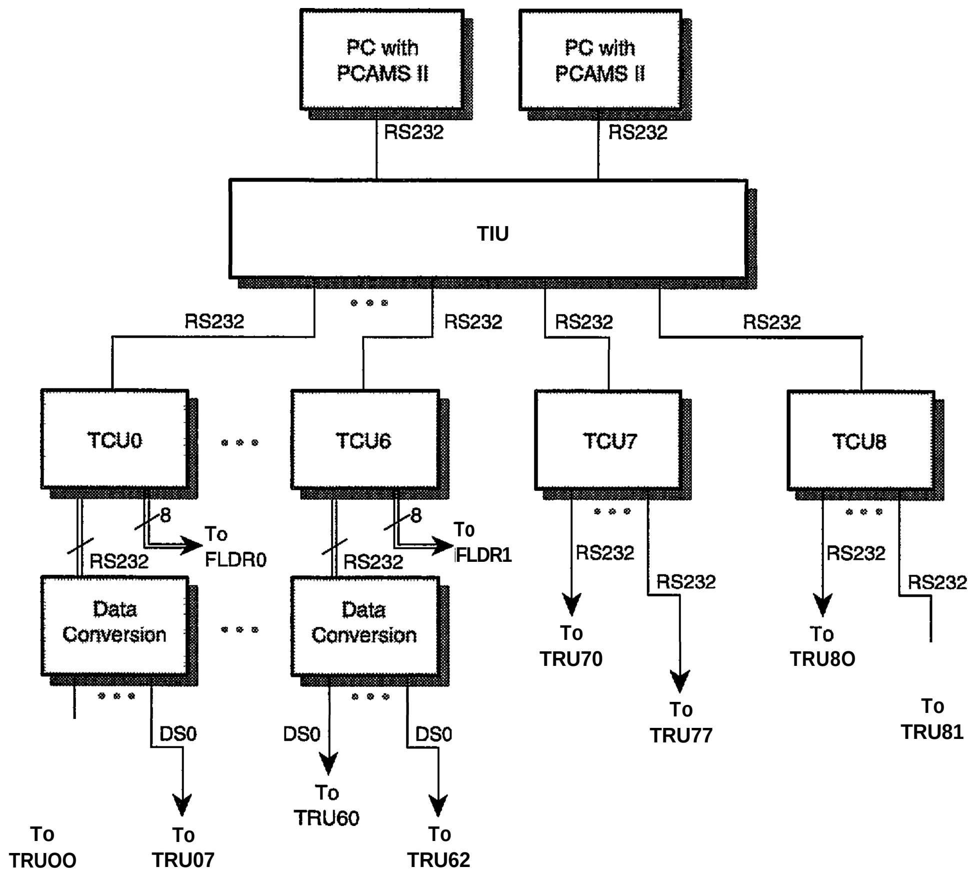


Figure 5.4.5-l - Network Management System interfaces

A TRU in each of the fiber hubs collects data concerning the status of each piece of equipment in the cabinet, as well as cabinet information such as temperature and door alarms. The information from each cabinet is transmitted along with Trans-Guide video and data via the optical fibers to the TOC, where information from the TRUs in the field (currently 51) is converted and transmitted to TCUs. These TCUs, as well as the TCUs connected to local TRUs, are all connected via a Terminal Interface Unit (TIU) to a PC running off-the-shelf network management software. The network management software alerts maintenance personnel whenever an alarrn occurs in any of the cabinets in the field. The network management software also provides the interface through which the communications equipment, both in the TOC and in the field, can be configured, provisioned, managed, and checked for performance or maintenance parameters.

In addition to the TRUs located in the field cabinets, there are also TRUs (currently 10) located in the TOC to monitor the communications equipment in the TOC itself. The TRUs in the TOC are connected directly to additional TCUs which, as mentioned above, are connected to the same TIU as the field equipment TCUs.

A separate set of hardware is connected to the NMS and used to alert TransGuide personnel of communications systems problems. The separate hardware is the Floor Lamp Display (FLD) system, illustrated in Figure 5.4.5-2. The FLD system is driven by the NMS. Eight contact closures in each of the TCUs associated with the field equipment are used. The contact closures are controlled by the NMS and are connected from the field equipment TCUs to two separate FLD TRUs located in the TOC. The FLD TRUs are connected to a FLD TCU which controls a lamp-based visual alarm system and a TDU. This equipment allows the FLD ID system to rapidly alert maintenance

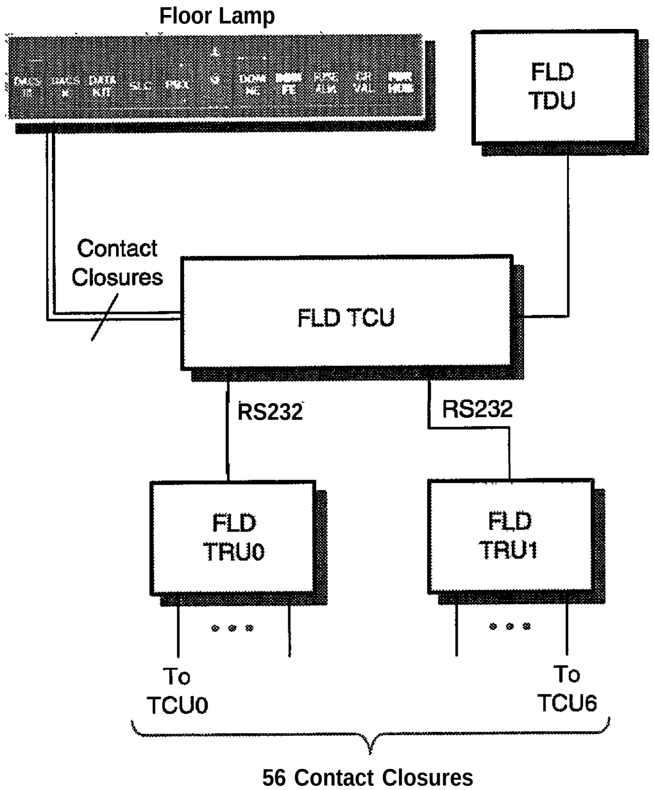


Figure 5.4.5-2 - Fiber Optic ID System

personnel of communications system problems using both an audible alarm and a lamp display easily visible throughout much of the communications equipment room

5.5 Computing System

The computer system and the software that operates on it are the heart of the TransGuide system. Several technologies were considered for the computer system and the workstations attached to it. For the computer system itself, technologies considered included high availability computers, distributed computing systems, and fault tolerant computers. Workstation options were intelligent workstations, X-terminals, and a combination of workstations and X-terminals. Various LAN configurations were also considered. When it became clear that the specified virtual circuit switch would not meet the requirements of the system, alternative methods to interface the computer to the field equipment were considered, including various terminal servers.

"One way to help the maintenance people is to provide a network management system. This is especially critical with TransGuide because TxDOT is primarily in the business of traffic operations. The lack of network management facilities for most of the other communications systems options (T1, coax, etc.) was one of the primary reasons for specifying the high-speed digital interconnection system. "

Member of TxDOT's TransGuide Design Team

5.5.1 Computer

Several types of computing systems were considered. Some of the computer types and relevant characteristics are listed in Table 5.5.1-1. The systems investigated included distributed control computers, networked workstations, high availability systems, and fault tolerant systems.

Many traffic control systems are based on distributed computers that each control a specific section of the roadway. This arrangement is usually the result of the system being developed a section at a time and often proves difficult to integrate into a smoothly operating system. The distributed nature of these systems provides some fault tolerance, but the loss of a single control computer may cause part of the traffic control system to cease functioning completely. However, even with the loss of a computer, much of the system should remain operational because it is controlled by other computers. Since these systems are often not interconnected initially, the most critical sections of the transportation system can be instrumented without having to install communications between sections. However, the distributed nature of the system also requires multiple, expensive operational facilities. Integration of independent operational facilities into a cohesive area-wide traffic management system may prove problematical.

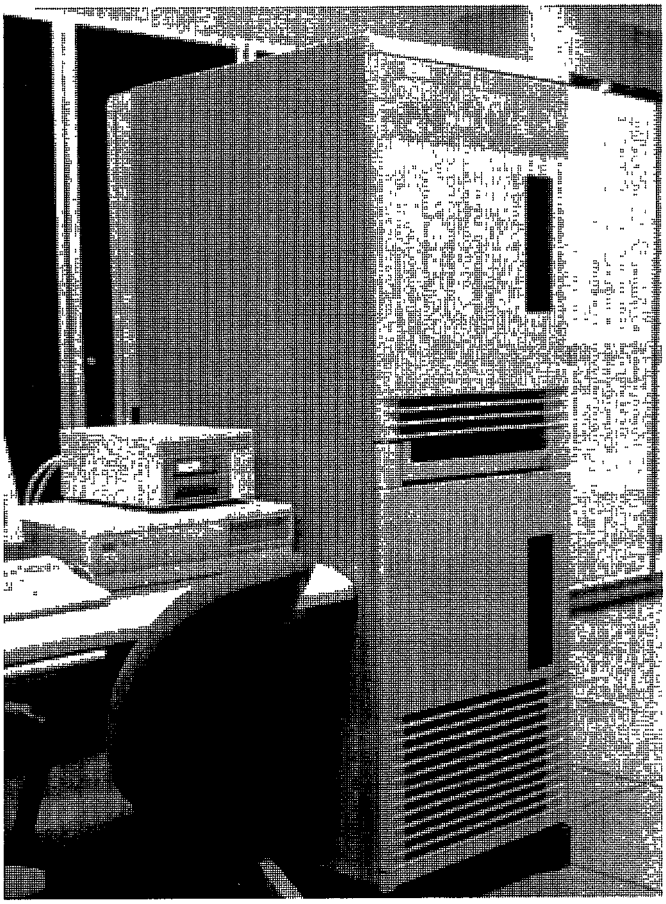
Using workstations as the computing elements in the system, but placing all of the workstations on a network at a single site, was one possibility considered. This architecture has the advantage of

TABLE 5.5.1-1 - Computer System Decision Matrix

Characteristic	Priority	Distributed Computers	Network of Workstations	High Availability	Fault Tolerant
Maintainability	Very high	Moderate, requires multiple location maintenance	High, can easily replace workstation while system continues to operate	Moderate, back on tine fast when there are failures	Very high, most of system can be replaced while the system is still operational
Reliability	Very high	Low on entire system, but high for most of the system	High, overall system should stay up almost all the time	Moderate, quality systems	Very high, almost no failures that affect system performance
Feasibility	Very high	High, can address one section at a time	Moderate, requires complex design, some risk	High, no significant effects on system complexity	High, little risk added by fault tolerance
Operational costs	High	High, due to multiple sites	Moderate, maintaining several, similar computers	Moderate, primarily off-line repairs	Moderate, infrequent, non-critical repairs
Availability	High	High overall, tolerates faults by losing sections	High for overall system, transitions required when workstations fail	Moderately high, back on line rapidly when the primary fails	Very high, repairs can be made while system is available
Installation costs	Medium	High, but can be spent in minimum size chunks	Medium, more workstations can be added as needed	Moderately high, **must** be included in initial purchase	High, must be purchased initially
Ease of integration	Medium	Low, difficult unless designed as a system from the beginning	Moderate, complex initial system design to maximize use of resources	High, no significant effects on system complexity	High, minimum added design complexity for fault tolerance

multiple computing elements, as does the distributed control architecture. If one of the computing elements fails, only a portion of the computing capacity of the traffic control center would be eliminated. Several implementations are possible with differing responses to failures. The system could continue with most operations with some diminished capability or with fewer highway sections under control. The system could also redistribute the load providing continued full capability for the entire transportation system, but with slightly slower responses. The primary disadvantages of the networked workstation architecture are the complexity of the system and the amount of communications required between the workstations. To provide high availability for the system as a whole, significant amounts of software complexity would have to be added to handle failure of the individual workstations. Significant amounts of interaction between the workstations would also be necessary to ensure that the responses to traffic incidents were well integrated. The efficient use of a networked workstation architecture would mandate a complex software environment that could distribute the sensor and control information correctly to each of the workstations. The software would also need to provide all operators with access to all information needed to initiate correct responses to incidents and would need to provide all operators with the capability to control any of the signs or signals needed to respond to incidents. Finally, the software would need to mediate control of cameras, signs, and signals between operators working on different computers.

A third computing system architecture considered was high availability computers. There are several levels of reliability and fault tolerance in computing systems. Some systems are well engineered, with wide margins of safety to tolerate minor changes in the environment or in power



Mainframe Computer

levels. They may also include various forms of fault tolerant memory,, self-diagnostic capabilities, and even software-based fault tolerance techniques. However, these systems all have single points of failure or require significant amounts of custom software to enhance their fault tolerant capabilities. Basing a system with the up-time requirements of TransGuide on a high availability system could leave it vulnerable to complete failure of the computer system at a critical tirne.

The computer architecture selected and specified for the TransGuide system and illustrated in Figure 5.5.1-1 is a hardware-based fault tolerant mainframe. The system is required to be fully fault tolerant. It must execute all instructions in parallel in separate hardware units referred to as zones. It must contain a high speed interface that allows it to compare the results of each instruction between the two zones to ensure that a fault in either of the zones is detected immediately. The system is required to be completely redundant. Even the backplane itself must be redundant. If a hardware problem occurs, the system must detect the problem and continue to execute the TransGuide software in the other zone without any loss of capacity. The architecture must allow parts of the computer system that have failed to be repaired or replaced while the other zone continues to operate the TransGuide system. Disk and tape drives, as well as memory and computational elements, must be repairable while the system is operating. These capabilities will provide a computing system that is capable of satisfying the up-time requirements of the TransGuide system.

While the system provides hardware fault tolerant capabilities, it must be capable of being viewed as a single uniprocessor running the operating system and the TransGuide applications. A single copy of the software is executed by both of the processors at the same time, with the results being compared to detect faults.

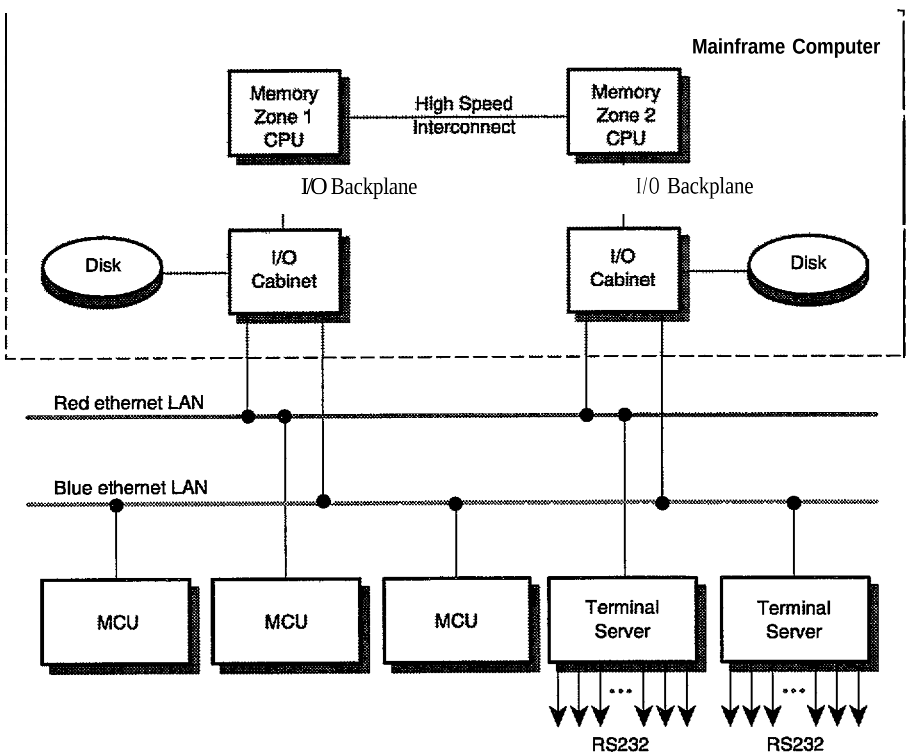


Figure 5.5. 1-1 - Fault-TolerantComputer

"Some people envision centralized systems as being able to sit at one terminal and talk to the individual systems which interfacing with the sensors and driver displays. The San Antonio system is envisioned as an integrated system that controls all of the various sensors and signs from a single system with as much automation as possible. "

Member of TxDOT's TransGuide Design Team

"The computer system is interfaced to the dual rail, fault tolerant LAN. It communicates through the LAN in a fault tolerant manner to the workstations and the terminal servers. Each of the two zones is connected via its own backplane and I/O card to each of the ethernet rails which make up the LAN. If one of the zones fails, the other zone can continue to interact with both of the ethernet rails.

5.5.2 Operator Workstations

Several types of equipment were considered for the operator interface to the TransGuide computer system. Some of the equipment considered is listed in Table 5.5.2-1, along with relevant characteristics. Among the types of equipment investigated were intelligent workstations, X-terrninals and X-terminals with hubs. Several factors were considered during the investigation, with the result that the user interface devices were specified to be X-terminals.

Intelligent workstations can, if properly programmed, minimize the memory and computational requirements of the mainframe and

TABLE 5.5.2-l - Workstation Decision Matrix

Characteristic	Priority	Intelligent Workstations	X-Terminals	X-Terminals with Workstation Hubs
Maintainability	Very high	Moderately high, independent systems, lots of repair experience	Moderately high, independent, reasonably simple systems, moderately common	Medium, More complex configuration, less independence and more types of systems
Reliability	Very high	Moderately high, single piece of common equipment per workstation	High, single simpler piece of hardware per workstation	Medium, more complex and single workstation hub could bring down several workstations
Operational costs	High	Medium, marginally higher than X-terminals	Moderately low, minimum	Moderately low, increased number of units but less capability required of mainframe
Installation costs	Medium	Medium, slightly more expensive workstations, but minimum mainframe memory and required bandwidth	Medium, lowest cost for workstations, but may require maximum mainframe memory and I/O bandwidth	Moderately low to medium, reduces mainframe memory requirements without costs of all workstations, however, may be maximum bandwidth requirements
Ease of integration	Medium	Moderate, requires software to update distributed information in real time	Moderately high, no real-time data updates, but requires intensive communications between mainframe and X-terminals	Moderate, requires software in hubs and mainframe to update distributed data in real time
Capability	Medium	High, workstations can relieve the mainframe of much of the computational workload	Medium, Most of the computational work must be performed in the mainframe	Moderately high, hubs can remove some of the computational work from the mainframe.

minimize the communications requirements between the mainframe and the workstations. However, the additional complexity required of the software to accomplish these tasks is significant. A straightforward implementation of the user interface for the TransGuide system would require a significant amount of communications between the mainframe and the operator's workstations. Intelligent workstations, in general, also cost more for the same display capabilities than X-terminals. The specification for the system required that the operator workstations contain operator interfaces with X-terminal capabilities. However, it did not exclude the use of intelligent workstations.

X-terminals provide a standard interface to multiple computers, which has been standardized so that terminals from various manufacturers will interoperate with computers from various manufacturers. Some of the intelligence required to provide the displays needed in the TransGuide system reside in the X-terminals and some of the intelligence lies in the computer. The standard interface to the X-terminals allows the system to be implemented using a set of available libraries and tools. Using these tools and libraries, the development process itself is considerably easier than developing custom interfaces between the computer and the user workstations. Depending on the implementation, X-terminals may require a significant amount of communication between the computer and the terminals. However, the development of the software to drive those communications is relatively straightforward.

One of the options considered during TransGuide system development was the use of hubs with X-terminals. The hubs could relieve many of the computational and communications requirements currently placed on the mainframe. The hubs could also minimize the memory requirements of the mainframe. However, the use of hubs would have required an added level of complexity in the development and implementation of the system software. The added level of complexity could have adversely affected software development. The hubs could have also been a single point of failure for the subset of X-terrninals that they drove. The number of single points of failure was minimized by the use of the hardware fault tolerant mainframe to directly drive the X-terminals.

Seventeen operator consoles are specified in the initial TransGuide system configuration. The allocation of those workstations is illustrated in Table 5.5.2-2. Eleven of the workstations are for the use of TxDOT personnel for management, training, R&D, and controlling traffic. Two of the workstations will be used by VIA, the local mass transit organization, and two of the workstations will be used by the police. The city itself and the fire department will each use one of the workstations to facilitate their response to emergencies. An additional 10 workstations can be added to the system to serve future needs.

5.5.3 Local Area Network

Several architectures were considered for the network to connect the computer to the operators' workstations and to the field devices. The architectures are listed in Table 5.5.3-1, along with relevant characteristics. The different options considered have a variety of fault tolerant capabilities, as well as a spectrum of other advantages and disadvantages.

An ethernet network provides a standard interface for computers and workstations and allows them to transmit and receive data at up to 10 Mbits

TABLE 5.5.2-2 - Workstation Allocation

Organization	Number of Workstations	Comments
TxDOT	4 Operators 4 Assistant managers 1 Floor manager 2 R&D &training 11 Total	- Four operators per shift maximum - Administrative - Also used as future growth workstations
VIA	2	
Police	2	
City	1	
Fire	1	
Total	17 27	10 additional workstations can be added

TABLE 5.5.3-l - Local Network Architecture Decision Matrix

Characteristic	Priority	Dual Ethernet, Dual Ports	Dual Ethernet, Mixed Number of Ports	Single Ethernet
Maintainability	Very high	Mixed, requires special hardware and specialized knowledge, but can be done with system operating	Moderately high, special requirements only for the computer, some or all of the system can remain operational during repairs	Moderately high, no special requirements, but system will be out during maintenance
Reliability	Very high	Very high, correctly operated should continue functioning through failures	High, at least some of the system can remain operational in the face of a failure	Low, failures can make system ineffective
Operational costs	High	Medium, replacing specialized hardware wilt be expensive	Low, no special requirements	Low to medium, additional staffing could be required to minimize down time
Equipment availability	High	Low, not normally available for all devices	High, all parts available	High, all parts available
Ease of implementation	High	Low, specialized hardware and software required	High, easy to implement using existing equipment and software	High, straightforward, no special requirements
Installation costs	Medium	Very high, requires specialized hardware	Medium, only requires additional cabling and ethernet cards compared to single ethernet	Low, no special or additional hardware required

per second. All the devices on a particular network segment share the use of a single cable which makes up that segment. The overall throughput of each segment is generally much less than the 10 Mbit per second maximum capability

The initial specifications required two ethernet networks connected by bridges. Each of the ethernet networks could be driven from either zone of the fault tolerant computer. Each of the devices on the network was required to have two ethernet interfaces. These devices included the X-terminals, the terminal servers used to control the field equipment, the high speed laser printer, and a terminal server associated with the video wall. With this configuration, the system could continue to communicate directly with any device, no matter what element in the computer or network failed. However, the implementation of such a system would have required a significant amount of custom equipment and software. Most off-the-shelf devices are not built with two separate ethernet ports. This option would also have required that the peripherals be capable of interacting with the dual ethernet scheme in concert with the fault tolerant computer to respond to failures anywhere in the system. Making the peripherals and the computer system interact in such a way would have required a significant amount of additional custom software. Overall, the implementation problems with this option overcame the fault tolerance it provided.

A second option was the use of a single ethernet LAN for all devices in the TOC. This option did not provide sufficient fault tolerance for maintaining the required system up-time. Even if both zones of the computer were capable of communicating to any of the devices over the LAN, a single failure in the LAN could make all of the user workstations unusable.

The third option consisting of two separate ethernet networks each connected to both zones of the computer and to a subset of the devices was selected. This option does not allow all of the operators' consoles and other devices to continue to operate in the face of some failures. However, it does allow approximately half of the operators' consoles to continue to be used with failures involving one of the LANs themselves. It also allows the continued use of all equipment when a failure occurs in one of the computer LAN cards or in one computer-to-LAN connection. This additional fault tolerance is available using the standard off-the-shelf capabilities of the computer system selected.

As the system is currently configured, it consists of two independent thick ethernet cables totaling more than 1000 feet. The thick ethernet cables are attached to devices (workstations, terminal servers, and the zones of the computer) via DELNIs. Each DELNI can replace up to eight transceivers, which connect devices to the thick cable. Under the selected configuration, a single failure may keep some of the workstations from being used and may block direct control of some field equipment. However, no single failure should take out all workstations or eliminate control of all field equipment.

5.5.4 Device Terminal Servers

The TransGuide system contains several types of field devices that must be driven by industry standard RS-232 interfaces. One RS-232 interface controls the pan and tilt for the cameras, as well as the focus, iris, and other remotely controllable attributes of the cameras. The LCUs, VMSs, and LCSs all have RS-232 interfaces. The communications system provides the capability of transmitting the RS-232 signals from the TOC to the field, but the RS-232 signals must still be generated. Table 5.5.4-l lists several mechanisms that could be used to generate the required RS-232 signals along with some of the characteristics of each mechanism.

The RS-232 signals could each be generated directly by the computer or by terminal servers, or the computer could interface to a virtual circuit switch to generate and distribute the signals to the appropriate devices in the field. Initial investigations indicated that each of these mechanisms had some advantages. However, thorough investigation revealed that only one of these mechanisms is feasible.

The use of the computer to directly generate the signals would be very straightforward. However, it is not feasible. The fault tolerant computer selected is intended to communicate to external devices only through mass storage interfaces or LAN interfaces. There are no facilities available for the computer to directly interface with a large number of serial, RS-232 devices.

TABLE 5.5.4-l - Equipment Communications Switching Decision Matrix

Characteristic	Priority	Virtual Circuit Switch	Computer Direct	Terminal Servers
Maintainability	Very high	Moderate, redundant, but a complex switch	Moderately high, no additional equipment except computer I/O boards	High, Very simple devices with easily added redundancy
Reliability	Very high	High, designed with redundant components	High, directly interfaced to the computer	High, simple device
Feasibility	Very high	Low, too slow	Low, requires too many I/O boards	High, no major problems expected
Switching time	Very high	**Slow,** not designed to support fast calls in a real time environment	None, a separate port on the computer for each piece of equipment	None, a separate port on a terminal server for each piece of equipment
Operational costs	High	Low, no major expected operational costs	Moderate, could be high for maintenance contract	Low, no major expected operational costs
Installation costs	Medium	Very high, requires single, high-priced system	Very high, requires many, expensive computer boards	Moderate, requires several low-priced, available components

A virtual circuit switch was originally specified as the interface between the computer and the communications system. The switch is designed to provide an interface between an ethernet LAN and a switched communications system. It is also designed to provide some redundancy in its operations. Initially, the virtual circuit switch looked like an ideal candidate for interconnecting the computer system and the field devices. However, the TransGuide system must poll each piece of field equipment on a regular basis to collect the data needed to detect incidents and to ensure that the field equipment is displaying the appropriate message. As discussed in the communications section, the virtual circuit switch requires more than a second to break each connection; therefore, it is not capable of switching rapidly enough to provide the system the capability to poll all of the field equipment within the required polling cycle **time.** It is not feasible to use the virtual circuit switch to interconnect the computer system and the RS-232-based field systems.

Terminal servers are devices that interface to a computer system via some high speed communications interface such as an ethernet LAN and provide outputs to multiple RS-232 type devices. The use of terminal servers to provide the interface between the computer and the field equipment will eliminate the need for switching. Each piece of field equipment will have a relatively permanent path through the communications system. Polling can then take place rapidly and the data can be collected and analyzed to detect incidents. At the same time, the display devices can be polled to ensure that appropriate data are being displayed.

Once terminal servers were in place to interface between the mainframe and the field devices, experiments indicated that the mainframe computer was spending a significant amount of its time polling the LCUs. In order to free up some of the mainframe's capabilities, dedicated Personal Computers (PCs) have been added to the system to poll the LCUs. The PCs collect the data from the LCUs and pass it on to the mainframe. The software in the mainframe which provides the capability to poll the LCUs will be left in place so that the mainframe can poll the LCUs if the dedicated PCs fail.

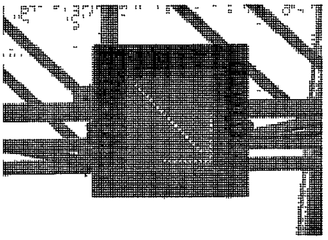
5.6 Driver Information Capabilities

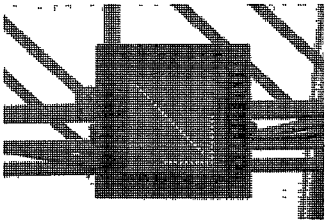
The primary purposes of the TransGuide system are to provide information to the drivers who use the freeway system and to control traffic. Three mechanisms are used to accomplish these tasks. Lane Control Signals (LCS) are located approximately every quarter mile along the instrumented areas of the freeway system. Variable Message Signs (VMS) are located before major interchanges, before level splits, and before some entrances to the freeway system. Both LCSs and VMSs are used to inform drivers of conditions and indicate which lanes are available. The timing of traffic signals on the access roads can also be modified to increase the flow of traffic diverted from the freeway

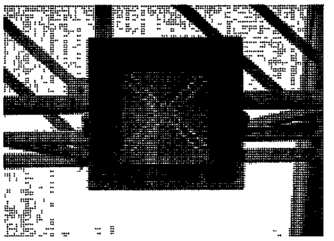
5.6.1 Lane Control Signals (LCS)

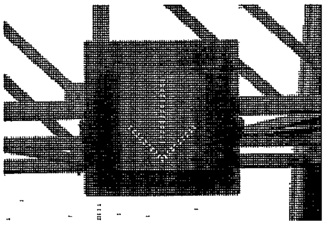
The LCSs are the most nurt-terous mechanisms for communicating with drivers. They provide limited, simple communications in the form of one signal for each lane of the freeway. The signal displayed for each lane can be a red X, a green down arrow, a yellow X, a yellow down arrow, a yellow slanted arrow pointing right, or a yellow slanted arrow pointing left. The red X indicates that the lane is closed. The green down arrow indicates that the lane is open. A yellow X indicates that the lane will be closed at some point downstream. A yellow down arrow indicates that the lane is open, but that there may be a hazard on an adjacent shoulder. A yellow slanted arrow pointing left or right indicates that the lane will be closed downstream and that the traffic should move into the lanes indicated by the arrow to find clear lanes or to exit from the freeway.

The contents of the LCS display are controlled by the TransGuide operators, either directly or through the initiation of scenarios. The LCS will normally display a green down arrow for all lanes that are not blocked. The other signals are displayed based on specific scenarios initiated by the operators. In general, blocked lanes will have a red X displayed by at least two LCSs in the lane upstream of the blockage. The use of a red X on two LCSs ensures that the motorist will see a red X in the lane even if one LCS fails. Upstream of a red X, at least one signal in a blocked lane will normally contain a yellow arrow advising motorists









to begin moving out of the blocked lane. Hazards on the shoulders will normally cause a yellow down arrow to be displayed upstream from the hazard. Each scenario is evaluated to determine the best configuration of VMS messages and LCS signals.

"If a lane is blocked, the scenario implemented should have two red Xs in that lane upstream of the incident. Before the two red Xs, one yellow slant arrow should be displayed. "

Member of TransGuide Design Team

The LCSs are composed of halogen bulbs, fiber optic bundles, color filters and lenses. Table 5.6.1-l shows some of the characteristics of the specified LCS. Two halogen bulbs provide the illumination for each color and color filters are used to produce the appropriate colored light. Fiber optic bundles carry the light to the face of the LCS, and lenses direct the light toward the drivers. The lighted dots are surrounded by a flat black faceplate to provide sufficient contrast so the segments can be clearly distinguished at 1/4 mile. Each of the indicators is illuminated by bundles coming from two bulbs, so the indicators can still be seen even if one of the bulbs is burned out. The LCSs are required to provide automatic dimming for night operation and

TABLE 5.6.1-I - LCS Characteristics

Characteristic	LCS
Max # of LCSs per gantry	6
Distance to be viewed	1/4 mile minimum
Angle to be viewed	12 degrees
Size of characters	18 inches
Brightness	20 foot-candles

to ensure that dimming does not turn off a bulb if the other bulb providing that color is burned out.

There are several mechanisms to ensure that the LCSs are capable of operating continuously reliably and affordably. An LCS can be polled by the system and instructed to report the status of each lamp. Most LCSs can be visually checked using the camera system. The LCSs are required to automatically report failed bulbs. The specifications require easy service access to LCSs, and TransGuide specifications place specific environmental compatibility requirements on signals. Finally, the specifications also specify long life requirements for the bulbs. These measures should help ensure that the LCSs operate continuously reliably, and affordably for many years.

5.6.2 Variable Message Signs (VMS)

The VMSs supply lengthier messages to drivers at critical locations on the freeway system. There are three different sizes of VMS used in the TransGuide system, as shown in Table 5.6.2-l.

Variable Message Sign ***(FMS) with the Default, Blank Message***

TABLE 5.6.2-l - VMS Characteristics

Characteristic	Type i VMS	Type 2 VMS	Type 3 VMS
No. of letters	15	18	12
Distance to be clearly viewed (feet)	1000	1000	400
Angle to be viewed	12 degrees	12 degrees	12 degrees
Size of letters (inches)	18	1 8	8
Rows of characters	**3**	3	2

Type 1 and Type 2 VMSs are intended for use over main freeway lanes. Type 3 VMSs are intended primarily for use at entrance ramps.

The VMSs used in the TransGuide system display characters formed by luminous dots in a five column-by-seven row matrix. Each of the dots is formed by the end of a fiber optic bundle (or two bundles in the case of the l8-inch characters). The ends of the bundles are revealed or covered by a shutter controlled by the sign's electronics. Selectively covering or revealing specific combinations of the dots displays any of the alphanumeric characters available on the sign.

The use of VMSs allows the TransGuide system to provide drivers with enough information so they can make informed decisions about travel routes and modes. Knowledge of the type of incident and its severity could significantly affect the driver's decisions.

5.6.3 Traffic Light Control

The traffic lights on access roads to the freeway system are operated by TxDOT. Those traffic lights can, therefore, be used to expedite travel when the access roads are required to handle full freeway traffic. The TransGuide system allows the operators, as a part of a scenario, to modify the mode of access road traffic lights when the traffic is being routed from the freeway onto the access road.

5.6.4 Distribution Of Traffic Information to Media and Other Users

A Media Distribution Plan, which facilitates the transfer of information from the TOC to media organizations (television and radio stations, print media) for dissemination to the travelling public, is incorporated into the TransGuide system. A primary reason for including the concept is that the TransGuide system maintains real-time data for the entire project area; data it is not possible for the media outlets to acquire except through the TransGuide System.

An industry advisory board was established to provide TxDOT with feedback from organizations that were identified as users of the available data. A series of five working group sessions were held to gather requirements and present design alternatives to the industry advisory board.

5.6.4.1 Data to Be Distributed

The TOC maintains a wide variety of data which can be used to determine current traffic conditions. The following data was identified as the most useful to the media organizations who transmit traffic conditions to the travelling public:

>Live video

>Graphical map (both the high level views and the lane level views)

*Scenario data (current state of the motorist warning signs)

*Lane closure data (scheduled construction and associated closures)

Specialized software was developed for TOC computers to extract the above data and prepare it for transmission to the end user. A single video source is dispatched but the video is actually a "round-robin" of TxDOT selected cameras. If only a single area of interest exists, the video can be dedicated to that area. If multiple areas of interest exist, then the video is switched between the areas on a time-shared basis.

5.6.4.2 Communication Alternatives

During the design phase of the Media Distribution Plan, the communications media displayed in Table 5.6.4-l were explored in order to provide the most useable communications solution. Due to the requirement to provide live video, a communication media with sufficient bandwidth to support full motion video had to be identified.

The different communications network approaches were discussed with the industry advisory board and it was concluded that Low Power Television (LPTV) was the most useable approach.

Although the initial focus of this TransGuide function is the media, it is envisioned that many other organizations will utilize the LPTV signal:

>Trucking and overnight package firms:

The LPTV data would be a very useful aid in the dispatching of vehicles because the data would allow optimal routing of vehicles for package delivery / pickup.

>Emergency services:

The data contained in the LPTV signal would be very useful to review while in transit so that both traffic delays can be avoided and, more importantly emergency personnel can observe the situation (through the video) before actually arriving on-site.

>Information kiosks:

Motels and malls could utilize information kiosks with the data from the LPTV to allow patrons to determine traffic conditions before they leave the facility where the kiosk is located.

>Large employers:

Many large companies have elaborate communications networks in place where employees could access traffic information (from a computer) if the company had access to the LPTV signal.

>Hospitals:

Emergency room personnel could prepare for incoming patients by observing the type and size of accidents. Advice from emergency room personnel could be based on better knowledge of the situation.

>Maintenance Personnel:

TxDOT, as well as city or county, maintenance personnel could make decisions as to equipment requirements based on video of accidents available at home. Early decisions on equipment requirements for accidents occur&g in the middle of the night may allow the freeways to be cleared before the morning peak period begins.

>Remote Operations:

Traffic operations personnel could use video at home, combined with remote capabilities to control the TransGuide system to respond to incidents which occur while the TOC is not manned. Traffic operations management personnel could also be consulted by on-duty personnel in unusual situations.

The LPTV concept, as shown in Figure 5.6.4.2-1, is a novel approach to broadcasting traffic information in a cost effective manner that can reach both stationary and mobil receivers.

5.6.4.3 Low Power Television Features

The Media Distribution Plan utilizes Low Power Television technology to distribute the data. The advantage of a Low Power Television station is that the information can be broadcast over the entire San Antonio metropolitan area and receiving the data requires a low cost UHF antenna and a decoder. The graphical map data, scenario data, and lane closure data are encapsulated and sent in the vertical blanking interval of the broadcast signal.

TABLE 5.6.4-1 - Media Distribution Communications Decision Matrix

Characteristics	Fiber Optics	Microwave	Low Power Television
Advantages	- In place network for major participants - lots of bandwidth	- Proven technology - Licensing easy to receive	- One time installation costs - Sufficient bandwidth - Signal can be widely received by low cost antenna
Disadvantages	- Limited access to fiber - Monthly subscription costs - Expanding network is expensive	- Need transmitter/receiver for each participant	- Signal quality effected by atmosphere - Limited range (based on terrain) - Need FCC License

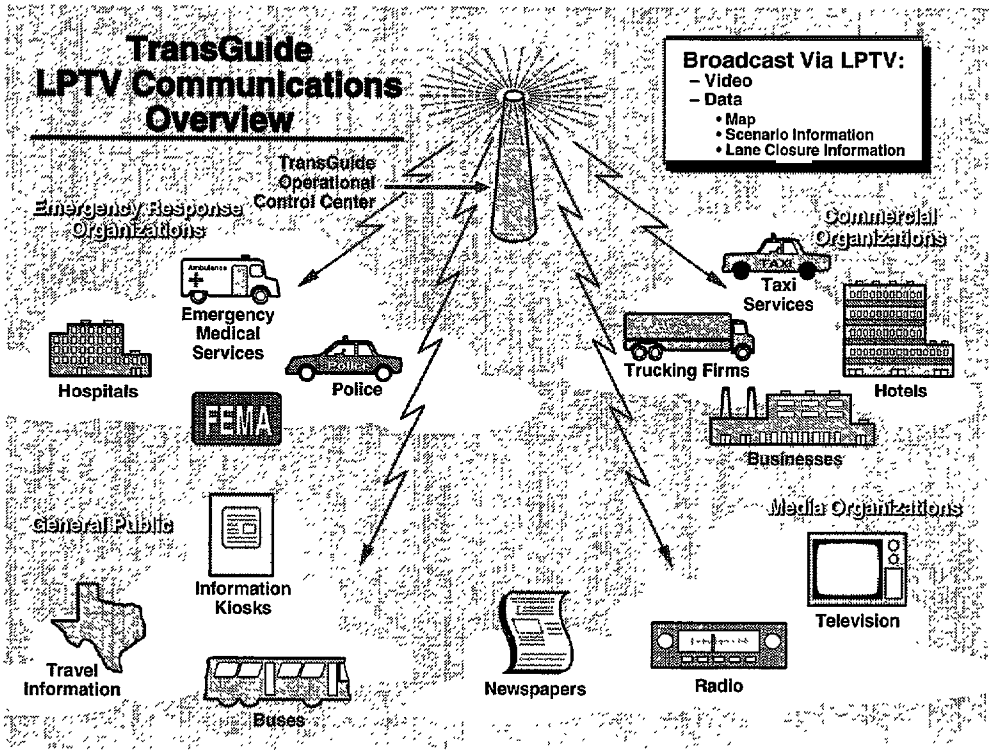


Figure 5.6.4.2-l - TransGuide LPN Communications Overview

The actual signal transmitted has been encrypted so that the general public can not view the raw video footage without a decryption device. The motivation for encrypting the signal was concern about children watching it and seeing inappropriate video footage.

TxDOT already maintains a 300 foot high tower which is capable of supporting the required transmission antenna. The data is gathered in the TOC and transmitted via a fiber optic cable (the video and digital data are still separate at this point) to the transmission tower. Using equipment installed near the tower, the digital data is inserted into the vertical blanking interval and the composite signal is then encrypted and dispatched to the actual transmitting antenna.

At each receiver site, a low cost UHF antenna is required to receive the LPTV signal. The signal is then decrypted and split into an NTSC video signal and a serial data string. The NTSC video can be viewed on an ordinary television receiver, on a computer screen with the appropriate video hardware, or recorded to tape for later review. The serial data can be decompressed and processed by an application program on a personal computer (PC). The data is displayed in a Microsoft Windows(TM) graphical user interface. Each data source (e.g. map, scenarios, and lane closures) is displayed in a separate window for which appropriate panning, zooming, and scrolling are provided.

5.7 Traffic Management System Interface

Since one of the primary goals of the TransGuide system is rapid detection of and response to incidents, it was incumbent on the TransGuide designers to define the overall operating procedures to facilitate the accomplishment of that goal.

Table 5.7-l lists several different traffic management system operational concepts. The operational concept selected for TransGuide has several unique attributes. Incidents are detected by a simple, parameterized algorithm. The parameters can be selected **to** provide the fastest possible detection time that has an acceptable false alarm rate. The manager or managers on duty can evaluate the alarm to determine whether it needs attention. If it does, the manager can assign the alarm to an operator who verifies the status of the incident, requests the aid of necessary emergency personnel, and provides feedback to the system as to the status of the incident. The system selects a scenario based on the operator's input, but the operator can

TABLE 5.7-1 - Overall Approach Decision Matrix

Characteristic	Priority	Traffic Engineers at Consoles	Traffic Engineer Pregenerated Scenarios, Technicians as Operators	Trained Operators, Traffic Engineer as Manager	Learning System
Response time	Very high	Moderately slow, responses must be generated for each situation	Very fast, selection and implementation time minimized for most situations	Slow, responses must be tailored and approved	Variable, initially slow, but faster as system learns more appropriate responses
Flexibility	High	Very high, traffic engineers can respond appropriately to each situation	Very high, scenarios can be generated to cover most expected situations, can also be combined or modified	Very high, response can be tailored for each situation	High, response can be tailored for each situation, but re-using responses may limit flexibility
Operational costs	High	Very high, requires experienced engineers as operators	Low, advantage of traffic engineer's experience without continual presence	Medium, some engineering presence required	Declining, initially significant engineering presence **required,** but not after the system comes up to speed
Time required for system to get up to peed	High	Low, No ramp-up	Low, scenarios can be generated before system is operational	Moderately low, some initial training required for operators	High, system must encounter problem before a scenario is generated
Initial effort required	Medium	Very low, minimum of advanced work or training required	Very high, scenarios must be generated for each potential situation	Medium, significant initial operator training will be required	Moderately low, some initial training, **but** little other initial preparation
Legal supportability	Medium	Moderately high, use traffic engineers, but under pressure	Very high, scenarios generated and approved by traffic engineers	Medium, non-engineers generate responses, approval under great pressure	Medium, non-engineers generating and selecting responses in real time

initiate or modify the scenario. If the scenario is modified, the manager must authorize scenario execution. If there are conflicts between scenarios, they must be resolved by a manager. When an incident has been cleared up, the operator cancels the scenario. The following sections discuss these operations.

Section 5.7.1 discusses the equipment available to managers and operators at the TransGuide workstations. Sections 5.7.2 through 5.7.6 discuss the mechanisms available to the managers and operators to deal with incidents on the freeway system, and Section 5.7.7 discusses the software required for operations, maintenance, and expansion of the TransGuide system.

5.7.1 Manager/Operator Workstations

The 17 manager/operator workstations installed in the TOC provide operators with all of the equipment needed to interact with the TransGuide system. Figure 5.7.1-1 shows the contents and interfaces of a typical workstation. Each workstation contains an X-terminal, generally referred to as a management control unit (MCU), four color video monitors, a telephone, and a two-way radio. Communications equipment to connect the workstations to the central computer is also provided.

The X-terminal built into each workstation allows the user, either a manager or an operator to interact with the computer. The terminal includes a 19-inch color monitor, a keyboard, a mouse, and a system box. The user can view maps of the city on the monitor at various magnifications and in two basic modes, high-level or schematic. The high-level mode provides more realistic distance and direction representations of the roadways, and the schematic mode provides direct access to TransGuide equipment by displaying a segment on the screen for each set of detectors. One segment is displayed for each lane. Using either the keyboard or the mouse, the user can maneuver through the TransGuide software to determine the status of and values reported by the detectors. The users are also alerted to alarm conditions and are able to control the video surveillance equipment and respond to incidents.

Using the X-terminal interface, users can control the video signals sent to the four 13-inch color video monitors surrounding the X-terminal monitor. The user can also control the cameras that produce the video, as well as the assignment of alarms and the selection and execution of scenarios to manage traffic. TransGuide mainframe software is designed to be used by the users via the X-terminals in the workstations.

5.7.2 Incident Assignment

The TransGuide system is designed to operate in either a lights out mode or in a manned mode. In the lights out mode, the data acquisition processes are executing but alarms generated are discarded because the control center is not manned. When the operational mode is changed to manned mode, at least one person designated as a manager must log onto the TransGuide system.

Any number of operators and other managers may also log onto the system. The TransGuide software partitions the city into sectors and each manager

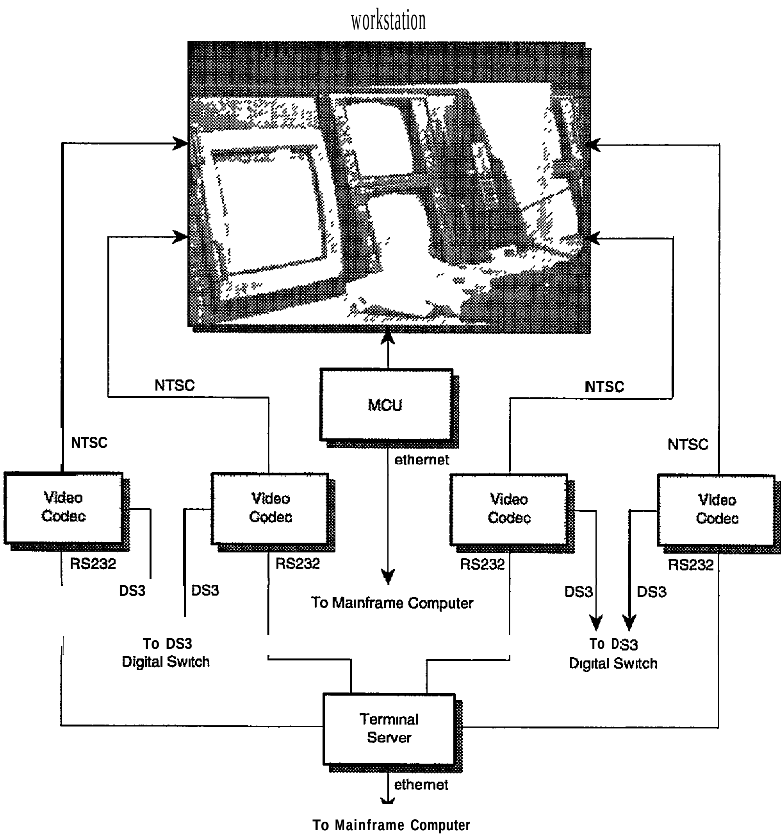


Figure 5.7.1-1. TransGuide Workstation Interfaces

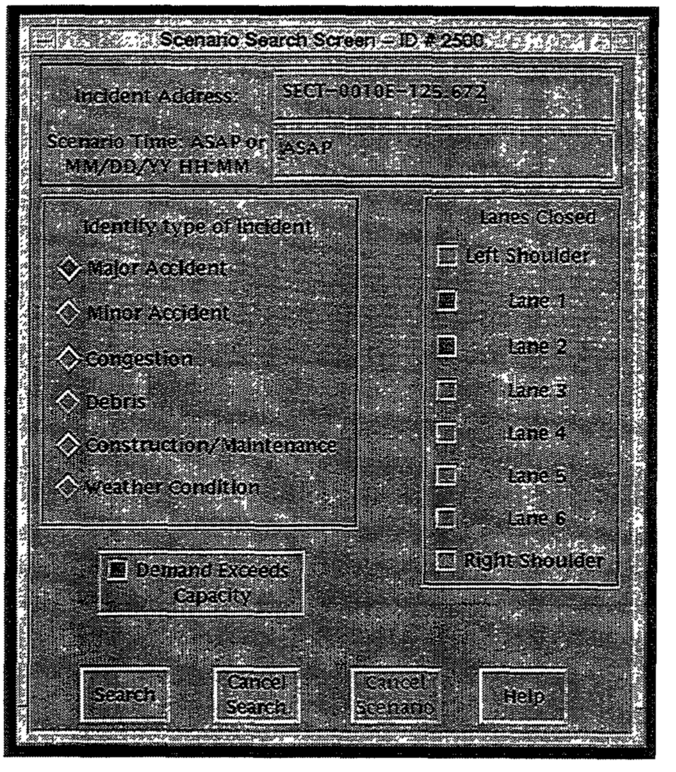
logged onto the system can be responsible for any of these sectors. When a manager is responsible for a sector, all alarms generated in the sector are first routed to that manager. The manager then makes the decision to either discard the alarm or assign the alarm to an operator for handling the incident (managers can also assign alarms to other managers).

In the default configuration, LCUs are polled every 20 seconds for their current running average speed, volume, and occupancy data. These data are used to compute two-minute moving averages of speed, volume, and occupancy for each lane at each detector location. The two-minute averages are compared to major and minor alarm values specifically selected for that lane, time, date, and day. If the two-minute averages cross either of the thresholds in either direction, an alarm is generated.

The manager of the section of freeway that generates the alarm receives notification of the alarm and its location. The manager can then access the camera(s) covering the section of the freeway indicated by the alarm to determine whether the alarm needs to be treated as an incident or not. When the manager accesses a camera, the system directs the camera in the general area of the alarm. The manager then has the capability of controlling the camera's direction, focus, lens configuration, and other attributes so the cause of the alarm can be determined. If the alarm is an anomaly that does not require any action by TOC personnel, the manager can cancel the alarm. If the alarm signals an actual incident, the manager can assign the alarm to any of the operators. Once the alarm has been assigned, the system notifies the operator. This notification overrides all other activities in which the operator may be engaged. The operator acknowledges the assignment by signing onto the alarm.

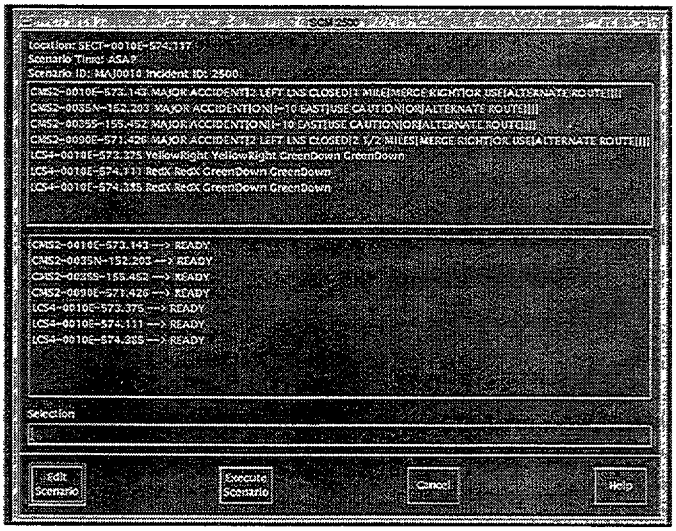
5.7.3 Scenario Selection Criteria

Once the operator has signed onto an alarm, the system provides facilities to allow the operator to easily access and control the camera(s) which overlooks the area of the freeway where the alarm occurred. The operator can use the system to point, zoom, and focus the camera(s) to get the best view(s) of the incident. The system also provides the operator with maps which allow access to much of the data available to the system. The operator, using a mouse, can indicate additional characteristics of the incident to the system. He or she can also use traffic data reported by the system, as well as video of the incident location, to generate inputs to the system. The operator indicates the type of incident, whether demand exceeds capacity, and the lanes blocked by the incident. The system then selects an appropriate scenario from a database of up to 128,000 preplanned scenarios based on alarm location and the information provided by the operator.



Scenario Search Screen

With a single mouse click, the operator can indicate whether the incident is a major accident, minor accident, congestion, construction, water, or debris. The distinction between a major and a minor accident is based on the estimated time required to clear the accident. An accident that the operator estimates can be cleared in 15 minutes or less is defined as a minor accident. An accident that will take longer to clear is designated a major accident. Incidents other than accidents are treated like major accidents, except that the system indicates on the message signs the actual type of incident.



"The operator indicates whether demand exceeds capacity, which lanes are blocked, and the type of incident that has occurred. Based on the operator's response, a specific scenario is pulled up by the system. The ability of the system to pull up a scenario is one of the primary distinguishing features of the TransGuide system."

-Member of TxDOT's TransGuide Design Team

By default, the system assumes that the capacity of the freeway is sufficient for the current traffic demand for each incident. However, a single mouse click allows the operator to inform the system that the freeway cannot handle the current demand with the current capacity.

The operator indicates which lanes of the freeway are closed by clicking the mouse once for each closed lane or once if all lanes are closed. Alternatively the operator can click once to set all lanes closed and then once for each lane that is open.

Overall, very few mouse clicks are required for the operator to indicate to the system all the information needed to select the appropriate scenario. When the operator indicates that the selection criteria have been completed, the system selects a specific scenario that matches the set of selection criteria determined by the location of the alarm and the operator's selections. The system presents the scenario to the operator. In most circumstances the operator will immediately, with a single mouse click, instruct the system to execute the scenario. However, if there are special circumstances requiring modifications to the scenario, the operator can make those modifications as necessary, before telling the system to execute the scenario.

The TransGuide system also allows users to schedule scenarios. This feature is important because many times scheduled events (such as sporting events) will cause traffic conditions that are predictable. The capability of addressing potential traffic problems before they occur allows TransGuide to be an active and not just a reactive system.

5.7.4 Scenario Execution

Once the operator instructs the system to execute the scenario, the system determines which of the actions in the scenario are unmodified and do not conflict with actions in place from previously executed scenarios. Those actions are immediately executed by the system. The systems goals are for those actions to be executed within 15 seconds of the time the operator initiates the scenario. The system communicates directly with the controllers for the LCSs and the VMSs affected and instructs them to display the appropriate scenario messages on the signs and signals. The system also polls the LCS and VMS controllers on a periodic basis to ensure that the signs and signals are displaying the correct messages. If the scenario has been modified, or if any of the messages from the scenario conflict with messages being displayed, the system allows the manager to provide necessary decision input.

"You want to be able to issue a scenario that is 99.99 percent accurate immediately, because if you wait for congestion to occur on the freeway before you react, then the back-up is so great that it does not matter what you do, you will not be able to handle the volume."

Member of TransGuide Design Team

If a scenario has been modified, the modified portions of the scenario will not be executed until a manager has approved the execution. This step ensures that the technician operators are not ultimately responsible for any of the messages displayed on the signs. The messages will either have been pre-approved during scenario development or specifically approved by a manager before they are displayed.

5.7.5 Conflict Resolution

If more than one scenario being executed contains messages for a particular sign or signal, the manager must determine the priority of messages. The message with the highest priority is displayed. The other messages are held in a queue. If the scenario associated with the highest priority message is canceled, then the next highest priority message is displayed. Once the manager has determined the priority of the messages, the system will instruct the relevant LCS or VMS to display the highest priority message.

If there is more than one manager on duty, the manager for the section of the highway containing the equipment, rather than the manager of the section containing the alarm, will resolve the conflict. The manager of the equipment section should have a better grasp of the best message to put on a sign. For example, a message about a backup on a downstream part of a different freeway may or may not be more important than a message about a local incident.

If the manager determines that more than one message must be displayed, the manager can cause the system to initiate a mode in which messages are alternated on a sign.

5.7.6 Scenario Modification

Depending on the circumstances, the scenarios generated ahead of time may not correctly cover all situations. If there are multiple accidents on a segment of the freeway, for example, there may not be a scenario to address the situation. The operator can modify the scenario, modify messages, and/or add equipment to be used, along with the messages for that equipment, for example, if an incident backs up past the signals and signs initially called for in the scenario being executed.

If an operator modifies a scenario, a manager must approve the modifications before they are actually displayed. The manager of the equipment for which messages have been modified is required to approve the modification. Once the modification has been approved, the system will display the modified message.

5.7.7 System Maintenance Functions

The software that drives the TransGuide system also contains many functions necessary for the system maintenance, modification, or expansion. Support software includes custom editors for each of the databases in the system, as well as for the map graphics. The software also includes required support functionality such as archiving and security.

Graphics editing capabilities allow the graphical maps to be kept up to date or expanded. Separate interfaces are available for operations personnel to make minor changes to the existing maps and for support personnel to make major additions to the maps for system expansion.

Two types of editing capabilities are available for the system's databases. Real-time editing to make temporary changes to messages or scenarios is available to both managers and operators. Permanent modifications can only be made by authorized personnel.

A real-time scenario editor is available to allow a manager or operator to create new scenarios for special functions. The scenario editor also allows a manager or operator to modify scenarios as needed. This functionality can be used to respond to multiple concurrent incidents, lengthening queues, unanticipated events, or other conditions requiring modified responses.

Several database editors are available to aid the manager in maintaining and expanding the system. A manager can use a separate scenario database editor to generate a new scenario to be placed into the scenario database. New scenarios can be added as the system expands or as a response to frequently reoccurring conditions. The scenario database editor can also be used to modify existing scenarios, if required, and separate database editors allow managers to add to or modify the equipment tables available to the system. Editors are available for the camera table, the VMS table, the LCS table, and the LCU table. Addresses and attributes of new equipment can be specified via the custom user interfaces available for each of these tables. Editors are also available to edit the message tables for the LCSs and VMSs and can be used by a manager to add to the messages displayable by scenarios.

Several database editors are available to aid the manager in operating the system. Some of them allow the manager to control alarm generation by modifying the thresholds used for generating alarms, the schedule for the thresholds, the monitoring plans, and the default polling and averaging times used by the system. Another editor allows the manager to modify the plans that control alarm assignment to different managers based on the location of the alarm.

The TransGuide system's archiving capabilities allow traffic data such as average speeds, volumes, and occupancies to be stored at 20-second intervals. This archival data can be used to analyze standard traffic patterns and evaluate the results of scenario implementation. The data can also be used as valuable input for the development of additional scenarios and the improvement of existing scenarios.

Integrated security features control the ability of various personnel to access or modify various system data structures. Core database information can only be modified by the system manager or someone specifically designated by the system manager.